Reconnaissance Watershed Analysis on the Upper and Middle Verde Watershed

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I. INTRODUCTION

A. <u>Background</u>

As a major water body and source for local and downstream supply, the Verde River and its watershed have been of concern for some time. However, to date the interest has been largely in the water resource use and development vein. This is well illustrated by a recent major document by the Arizona Department of Water Resource, "Verde River Watershed Study," which stresses existing water uses and water supply.

The Verde Watershed Association has also recognized the upland, on-land, and smaller scale water resources as important. That is, the quality, quantity, and timing influences on water generated as the result of land uses and condition at local scales. While these are felt clearly on upland source areas and smaller streams, their collective actions operate throughout the entire watershed. This "watershed" approach is also germane to current efforts to control non-point contributions to downstream water quality, and is the increasing target of environmental regulation.

Conditions in the Verde watershed have changed since settlement. Early European settlers in the Verde Valley reported the Verde River to be a slow meandering stream with many quiet, even “swampy”, backwaters. In fact, the first Fort Verde military encampment was moved further from the river because of the prevalence of mosquitoes and incidence of malaria. There were reports of grass "up to a horse's belly" and some of the earliest settlers cut native grasses as hay for a livelihood. Subsequent human use, along with climatic cycles and extreme natural events resulted in changes to the river and to portions of the watershed. Today there is a range of views and opinions on the condition of the watershed and how it functions in the hydrologic cycle.

One point on the spectrum is that the intervening years of livestock grazing over most of the watershed, fire suppression, timber harvesting with associated roads, mining, urbanization, and other human uses have resulted in a significantly changed hydrologic condition. This has led to a greater portion of precipitation running off the surface rather than infiltrating into the soil, with higher and more frequent floods, lessened groundwater recharge, degraded water quality, with more soil erosion but lessened dry season stream flow. Correspondingly, with less infiltration, the uplands are less productive than formerly.

An alternative view might acknowledge the land use effects, but point out that they are dwarfed by the magnitude of natural climatic variability, and contend that the river integrates all of the watershed's influences and adjusts its channels accordingly. Albeit there is a little more soil erosion; however, the multitude of impoundments, primarily livestock watering facilities, capture the majority of the increase, and stream turbidity derives primarily from localized streambank erosion and the natural drought to flood cycles in the Southwest.

These issues and their potential influence on public policy lead directly to the basic questions, "What is the condition of the watershed and what effects does this have on the water resource?", and "What opportunities are there to make improvements that would better meet objectives?"

To service these questions, the Verde Watershed Association in a document entitled, "Upper Verde Watershed Problem Statements," dated April 19, 1999, itemized its consensus information needs. This listing arose from a solicitation of Association membership and public contributors. Of significance here are the following excerpts relating to watershed management:

Watershed Influences
3. “There is a need to perform a comprehensive watershed condition and trend assessment, and perform analyses on identified concerns.
4. There is a need to understand land use practices and their relationship to water quantity and quality. …"

B. Area of Analysis

The Upper and Middle Verde Watersheds have been delineated by the Arizona Department of Water Resources. The Upper Verde Watershed is the watershed which drains to the USGS stream gage number 09504000, titled Verde River near Clarkdale, Arizona. It does not include the closed Aubrey Basin. This gage site is located just downstream from the confluence of Sycamore Canyon with the Verde. The portion of this watershed which is located within the Prescott Active Management Area is not included in the major part of the analysis; however, there are some references to portions of it as relevant to discussions of the remainder of the watershed.

The Middle Verde Watershed drains to USGS stream gage number 09506000, Verde River near Camp Verde, Arizona. The gage site is located just upstream from the confluence of Chasm Creek with the Verde. The watershed is the area which drains into the Verde River between the Clarkdale and Camp Verde gages.

The majority of the report will address the Upper and Middle Verde watersheds (less the Prescott Active Management Area, except where it is needed and relevant to the analysis and discussion, e.g., streamflow amounts at the Paulden or Clarkdale gages.) The term “the watershed” will denote the combined area. Total area as derived from the Arizona Land Resource Information System, GIS database, using Arizona Department of Water Resources boundaries for watershed area, is approximately 4,350 square miles. (The USGS reports a contributing drainage area to the Verde River near Camp Verde of 4,645 square miles. However, that includes a portion of the Prescott AMA which is not included in this watershed area.) Table 1 illustrates land ownership:

Table 1. LAND OWNERSHIP BY PERCENT OF AREA

	Upper	**Middle**	**Combined**
National Forest	50.11	88.03	63.25
State	13.52	2.73	9.78
Private	34.94	8.85	25.9
Military	1.42	0	0.93
Other	0.1	0.39	0.14

Three National Forests – Coconino, Kaibab, and Prescott – comprise 63 percent of the combined watershed area. Private land and Arizona state trust lands make up nearly 50 percent of the area in the Upper Verde, the majority of it being in the Big Chino Valley area. In the Middle Verde the private land is mostly in the Verde Valley between Clarkdale and the Camp Verde area.

C. Methodology

The scope of this study has been to compile, analyze and synthesize a wide variety of existing information, with only a small portion of the effort devoted to collection of new data or information. To that end historic literature references – books, newspapers, journals have been a source. These have been supplemented with information from land management and natural resource agencies. As is commonly the case, there is not the luxury of having site-specific scientific studies on all relevant facets of geologic, climatic and vegetation history. Some degree of extrapolation from studies in adjacent watersheds or at least in the same general regional climatic regime has been necessary. Where there is site-specific information it is so identified.

In evaluating existing condition, the data, along with methodology of analysis, are referenced and analysis assumptions documented. Information is presented in an essentially chronological manner until the present time period. As is often the case in new, or inexact, science disciplines, there is frequently a difference of interpretation between research scientists. Sometimes this appears to be due to the evolution of new and expanding information and understandings. Some others seem to be at least partially a result of different paradigms associated with different disciplines, e.g., the relative influence of humans on landscapes as viewed by geologists or climatologists versus by anthropologists. Where there is a clear difference in interpretation we have attempted to present these views, compare and contrast them and describe any additional information which bears on drawing conclusions from them.

There has been an attempt to relate land uses with conditions, if not necessarily in a cause and effect relationship, at least in the context of relative time periods. However, we are aware that synchronicity does not necessarily denote cause and effect.

Finally, because there are so many different reports, descriptions, etc. this report does not attempt to repeat detailed descriptions of geology, climate, vegetation, land use, etc. but relies on references and summaries. Descriptions are limited to that necessary to put the analysis and discussion in context.

Tables 2 and 3 summarize statistics for vegetative types by ownership and associated geology.

	TABLE 2. ACRES BY VEGETATION AND/OR LAND USE – UPPER AND MIDDLE VERDE WATERSHEDS										
Owner-ship	**Pinyon-Juniper**	**Grass-land**	**Ponderosa pine, et al**	**Chaparral, AZ cypress**	**Desert Shrub-Grass**	**Riparian**	**Water**	**Agric**	**Urban Develop**	**TOTAL**	**Percent of Area**
State Trust	157912	77578	22652	3074	9375	86	1072	272	356	272378	**9.8**
Private	406264	196107	32583	22262	21612	2259	1586	10099	28565	721337	**25.9**
National Forest	773415	58939	602361	204630	113030	3398	1927	1213	2446	1761360	**63.2**
Military	0	0	25751	0	0	0	0	0	121	25872	**0.9**
All Other	136	67	69	633	1871	185	82	158	778	3978	**0.1**
TOTAL	1337727	332691	683417	230598	145888	5928	4668	11742	32267	2784926	**100.0**
Percent of Area	**48.03**	**11.95**	**24.54**	**8.28**	**5.24**	**0.21**	**0.17**	**0.42**	**1.16**	**100.00**	

Data from Arizona Land Resource Information System, GAP vegetation and landownership components

TABLE 3. ACRES BY GEOLOGY AND VEGETATION/LAND USE - UPPER AND MIDDLE VERDE WATERSHEDS											
Geology	Pinyon-Juniper	Grass-land	Ponderosa pine, et al	Chaparral AZ cypress	Desert Shrub-Grass	Rip-arian	Water	Agric	Urban Develop	TOTAL	Percent
Quaternary Surficial	95409	102002	0	2476	9499	571	329	4307	8819	223412	8.0
Percent	42.7	45.7	0.0	1.1	4.3	0.3	0.1	1.9	3.9	100.0	
Quaternary & Tertiary basalts & volcanics	541366	129656	557680	23673	26719	892	2434	1549	3408	1287377	46.2
Percent	42.1	10.1	43.3	1.8	2.1	0.1	0.2	0.1	0.3	100.0	
Tertiary sediments	169832	38897	346	72431	103250	1641	702	4856	11268	403222	14.5
Percent	42.1	9.6	0.1	18.0	25.6	0.4	0.2	1.2	2.8	100.0	
Paleozoic sediments	453024	58949	122201	100974	6155	2824	1201	1030	8772	755131	27.1
Percent	60.0	7.8	16.2	13.4	0.8	0.4	0.2	0.1	1.2	100.0	
Granitoid & metamorphic	78095	3188	3190	31044	264	0	2	0	0	115783	4.2
Percent	67.4	2.8	2.8	26.8	0.2	0.0	0.0	0.0	0.0	100.0	
Total	1337727	332691	683417	230598	145888	5928	4668	11742	32267	2784926	100
Percent	48.0	11.9	24.5	8.3	5.2	0.2	0.2	0.4	1.2	100.0	

Acres from Arizona Land Resource Information System, Gap vegetation component, and aggregated geologic components from statewide coverage.

II. HISTORICAL USES AND CONDITIONS

A. Climatic Trends

In order to properly consider the current conditions and how they might be affected by the nearly one and a half centuries of European settlement and use, it is helpful to have a longer term context. Although geological studies describe conditions extending back hundreds of million years, a time period with more suitability for consideration seems to be the Holocene which makes up approximately the last ten to twelve thousand years. Coincidentally, this is the same time period for which the alluvium has been legally defined as hydraulically connected to flowing streams in terms of surface water law in Arizona.

The Holocene, or last portion of the Quaternary, itself the last part of the Cenozoic, occurred following cessation of the most recent episode of the Ice Age or southward advances of glaciers in North America. Several studies have attempted to describe the changes in climate and how they have affected vegetation and, in turn, the soil surface and its vulnerability to erosion as well as the cycles of degradation and aggradation in stream channels (Allen, Betancourt & Swetnam,1998; Antevs, 1955; Van Devender, 1987).

Van Devender (1987) analyzed pack rat middens from southwestern Arizona for the last 14 thousand years and concluded that changes in vegetation over that period reflected a climatic change to warmer winters and wetter summers.

Allen, Betancourt, and Swetnam (1998) describe the differences in southwestern vegetation between the end of the Pleistocene about 12,000 years ago and the current situation. Spruce-fir, mixed conifer or sub-alpine forests covered much of the area occupied today by pinyon-juniper woodlands. Ponderosa pine was virtually absent and packrat midden records indicate it has come into the southwest only in the last few thousand years. They point out that migration of plant communities, e.g., movement of the pinyon-juniper type northward and up-elevation, initiated early in the Holocene, may still be ongoing.

Several paleoclimate studies have been conducted with sediment cores from natural lakes within and adjacent to the watershed. They include Potato Lake just outside the southeast corner of the watershed (Anderson, 1993), Stoneman Lake (Hasbargen, 1994) and Pecks Lake in the Verde River corridor (Davis and Turner, 1986). These generally agree on paleoclimate trends in the last few thousand years and their effect on vegetative communities. The Stoneman Lake study reported pinyon and juniper pollen beginning to increase about 3,500 years ago, suggesting expansion of woodland at the expense of ponderosa pine forest. The Pecks Lake study found that the percentages of juniper pollen began to gradually increase more than 2000 years ago but the rate of increase abruptly accelerated after introduction of livestock grazing.

Antevs (1955) reviewed both geologic and biologic indicators and cited a series of droughts in the last several thousand years. He concluded that the most severe and extensive drought of the last 4000 years was from about 1276 to 1299 and that it contributed to significant arroyo erosion in the Southwest and that another major drought occurred in 1573-1593.

Swetnam and Betancourt (1998) concur with an extreme drought of 1575-95 and add that the most severe drought since that time was 1942-57. Droughts and wet periods affect episodes of recruitment and mortality in plant communities. They describe 20th century climatic trends in the southwest as including wet winters in the early part of the century (1905-1930), a mid-century dry period of 1942-64 and the last quarter of the century beginning in 1976 as characterized by warm, wet winters and erratic summers. They found that tree ring width for a variety of conifers in this last quarter century was unprecedented in the last one thousand years.

Ely, et al (1993) and Ely (1997) evaluated flood history over the last 5,000 years in the Southwest and reported fluctuations in frequency of "extreme floods" apparently correlated with changing climatic conditions. They reported that frequency of these floods increased during periods of relatively cool, wet climate while generally warmer periods had reduced frequency. The last 600 years showed an increase in flood frequency with the early part of the 20th century being a period of "anomalously high streamflow and floods in the southwest…". They also found a correlation with periods of more frequent El Niño events.

Several paleohydrology studies have been conducted on the lower Verde in the last 20 years. Ely and Baker (1985) reported at least one flood within the last one thousand years with a peak flow substantially greater than the largest (1891) since records began. Subsequently, House, et al (2001) studied a reach a few miles downstream and reported deposits of 11 major floods in the last 1600 years, with two appearing to be slightly larger than the 1891 flood.

More recently Huckleberry and Cornmeyer (2002) studied the Verde River within the middle Verde Valley between Cottonwood and Camp Verde. They found evidence of a number of large floods in the last 1000 years with the greatest frequency in the last 600 years. They also pointed out that 7 of the 10 largest flood peaks since stream gage records and flood calculations began in the late 1880's have occurred since 1978, a period with documented El Niño episodes.

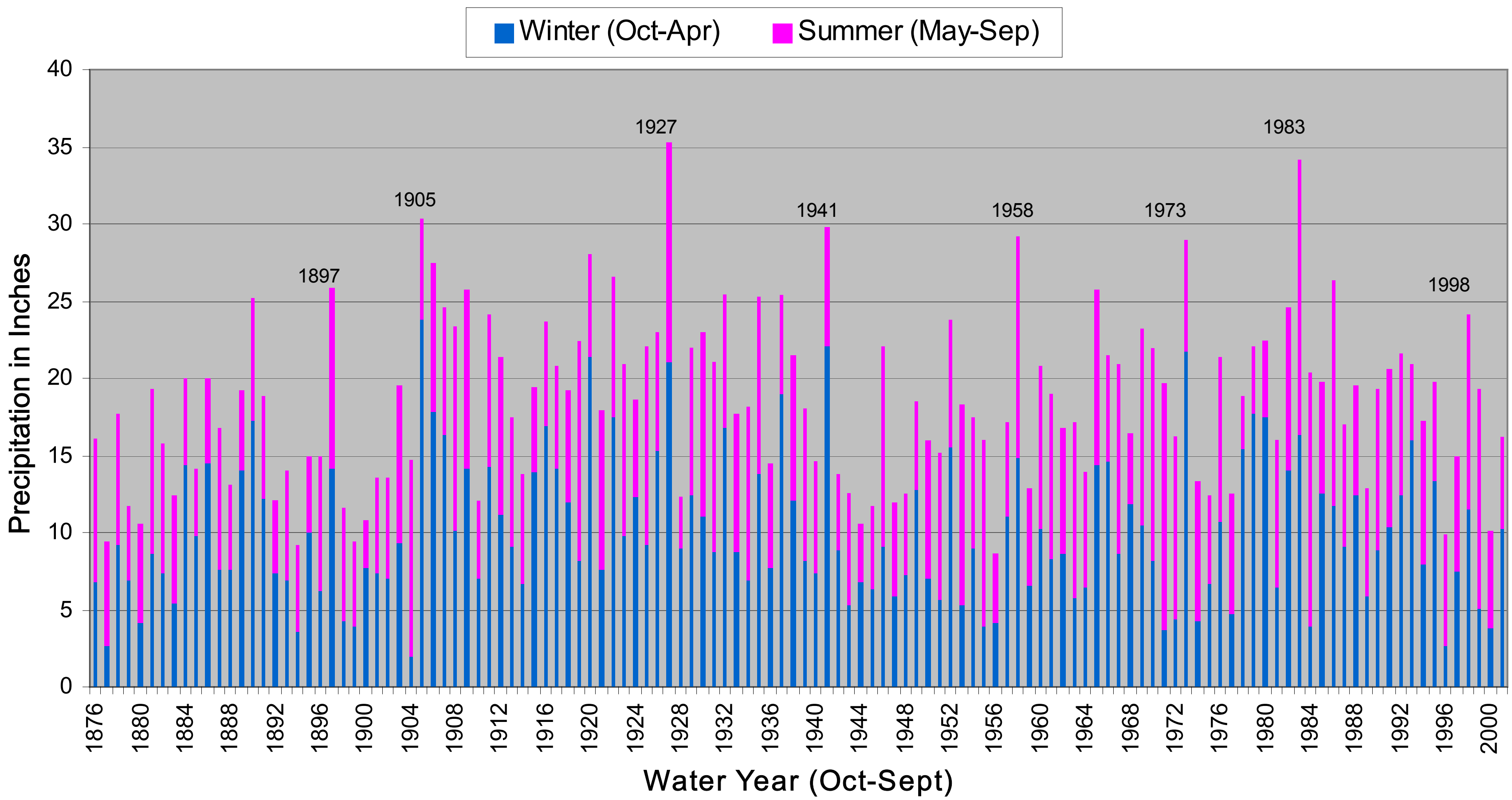
The arroyo formation discussed by Antevs (1955) was further evaluated in southern Arizona by Waters and Haynes (2001) who looked at arroyos in alluvial valleys of the Santa Cruz and San Pedro valleys. They found evidence of seven different cycles of arroyo cutting and aggradation in the last 8,000 years, with three being in the last 1,000 years – the most recent around the turn of the 20th century.

Neilson (2001) described the most recent climatic period as favoring shrubs and woody species due to the influence of increased winter precipitation. He added that the climatic regime most commonly predicted with global warming would continue this trend.

Figure 1 illustrates precipitation in Prescott for water years from 1876 through 2001. It is divided into winter (October-April) and summer (May-September) seasons.

Figure 1.   Prescott Precipitation 1876-2001

Water Year 1876 is October 1875 through September 1876, etc.



As can be seen from Figure 1, precipitation for several years around the turn of the 20th century was very low, similar to that at the turn of the 21st century.

Leiberg (1904) in describing conditions of the San Francisco Mountains Forest Reserve when examined in 1901 and 1902 refers to both Mormon Lake and Stoneman Lake being dry, "…eight years ago both were full, Mormon Lake having a depth of 10-15 feet and being plentifully stocked with fish." Likewise, Plummer (1904) in discussing the Black Mountains Forest Reserve in 1903 refers to an eight year drought and its effect on "yellow pine, alligator juniper and Arizona cypress, which trees, as a rule, stand an extreme drought."

B. Pre-European

One of the earliest effects was the use of human ignited fire supplementing natural lightning caused fire. Dobyns (1981) cites references of hunting with fire drives by a number of tribes including Yavapai, Western Apache, Walapai (Hualapai), and Navajo.

Although the effects of humans on the ecosystem prior to the 1860's in the Upper and Middle Verde watersheds are not well documented, Dobyns describes effects in the Gila drainage further south in Arizona, including the San Pedro and Santa Cruz drainages, as well as the Gila mainstem and adjacent smaller tributaries. Besides the use of fire, he discusses water management structures -- including rock check dams, rock terraces, and pole and brush diversion dams constructed by prehistoric Indoamericans. He cites references to low earthen dams with shallow ditches to spread waters from small ephemeral drainages at the point where the drainage gradient was reduced "at the foot of a sloping catchment basin". He states that these were most numerous and extended into tributary areas in areas of heavier population density where more land was needed for agricultural production. The degree to which the practice was present in the Verde is not documented; however, Pilles (2001) believes it was present to some degree.

Dobyns also cites the widespread gathering and use of fuelwood for roasting agave and other foods, heating, etc. as having some impact on tree cover and contributing to a greater presence of grass and herbaceous species.

C. European Use and Settlement

Human effects on the ecosystem are best known and documented from the European settlement period which was from the 1860's forward. Although the area was under Spanish and Mexican jurisdiction until the Spanish-American war in the mid-19th century, actual European settlement began following the discovery of gold in the Prescott area during the Civil War. Spanish visits to the watershed are documented in both the 16th and 18th centuries (Byrkit, 1978); however, no attempts at settlement are known.

Although the period of Spanish colonization of the Southwest had few direct effects on the Upper and Middle Verde watershed there may have been indirect effects. Dobyns (1981) cites drastic depopulation of native peoples as a result of epidemic smallpox introduced by the Spanish in the 1520's, followed by a measles epidemic in the 1530's. He cites estimates of up to 75 percent or higher mortality among these people. As a result, he believes that the area needed for agriculture, as well as the number of people available to practice it, shrunk accordingly and only the most productive areas along major streams continued to have water management structures maintained. Again, the degree to which this applied to the Upper and Middle Verde is not known. Both diseases were apparently very virulent and transmitted between groups through contact which could have included trade.

Both Dobyns and Whittlesey (1997) emphasize the importance of beavers and their dams in affecting stream hydrology and stability and the impact of removal by trapping. Again most of the detail is in southern and southeastern Arizona; however there are references to at least two groups trapping the Verde from its confluence with the Salt to its headwaters in the late 1820's. Dobyns postulated that the beaver population had been almost eliminated by the mid 1830's. Apparently any such removal in the Verde was not permanent, as in 1864 Allyn describes the headwaters of the Verde north of Del Rio Springs as,

> "where beaver dams form a succession of ponds that are literally filled with fish."

There were also reports of numerous beavers in the Verde Valley when Euroamerican settlers first came in.

The next phase of human impact began with the discovery of gold in the Prescott area in 1863. Discoveries in the Hassayampa and Lynx Creek drainages, just outside the Verde watershed, led to an influx of miners, followed by settlers, then soldiers to protect the miners and settlers from the natives who were being displaced by the newly arrived Euroamericans. Arizona's first capital was temporarily in the vicinity of Del Rio Springs, but shortly moved to Prescott. Agriculture (predominantly livestock grazing), mining, and lumbering were the primary industries affecting the area in the latter part of the 19^{th} century.

A great deal has been written about the effects of heavy livestock grazing (e.g., Croxen, 1926; Whittlesey, 1997; Willard, 1976) in the late 1800's and its relation to subsequent changes to both the upland watersheds and river/riparian corridors in both the Southwest in general, as well as the Verde Valley (Middle Verde watershed) in particular. Some writers attribute changes to a combination of climatic conditions and human impacts (Hastings and Turner, 1965). Others strongly insist that the changes are predominantly of anthropogenic cause (Dobyns, Whittlesey). This report does not settle the arguments as to the relative degree of human caused changes. Information found and reported is presented and discussed.

As discussed under Climatic Trends, periodic flooding of the Verde River was occurring prior to introduction of livestock in the watershed. Joseph Pratt Allyn reported on experiences in Arizona between 1863 and 1866. He was a judge appointed by President Lincoln to accompany the first territorial governor following establishment of Arizona as a territory. In March 1864 he accompanied an exploratory party traveling from near Prescott to the Verde River and then down the Verde. (At this time there had not yet been any European settlement in the Verde Valley.) They reached the Verde River in an area believed to be either along Gap Creek or Chasm Creek but could not cross the river there.

> "The Verde here is a fine rushing stream, some fifty yards wide, and not fordable; it is dammed just below with drift wood. We have struck the river in the canon between the upper and lower valleys, and it will be difficult to get out."

The party turned back uphill and after three hours, due to the crossing of intervening drainages, reached the river at the lower end of the Verde Valley where he observed,

> "The terrible floods of two or three years ago have furrowed this valley with channels, paved it with smooth round stones, and strewn it with drift wood. The volume of water must have been immense, the stream there perhaps a mile wide. There is an abundance of cottonwood trees and mesquite bushes."

The most recent floods had most likely been two years prior, in January 1862. Dobyns cites reports of a major regional storm and flooding in the Southwest being the greatest in the most recent 30 years on the Gila. (Citing this same quotation, Whittlesey says,

> "Destructive flooding of the modern era seems to have been initiated along the Verde River in the mid – 1860's.")

In January, 1874 another major storm occurred and caused flooding in Granite Creek near Prescott where the Fort Whipple rain gauge measured 3½ to 4 inches in a five day period (Dobyns 1981). Flow in the Verde River near Camp Verde was described as being very destructive,

> "…sweeping away a dam and seriously injuring a ditch, built by the troops to supply the post with water."

As has been the case in some of the recent flood years, e.g., 1993, the January, 1874 flood was followed by another very large storm and flood in February. The Prescott newspaper reported that the

> "oldest settlers declare this storm exceeds in severity and duration any previous one in northern Arizona."

In June, 1879 Charles Douglas Willard and his brothers drove a herd of cattle into the Verde Valley from the northwest, reaching the river near present day Clarkdale. Seventy years later in writing of the early days he said,

> "At that time there was no such a thing as erosion anywhere. The river channel was just wide and deep enough to carry the water in the summertime. And so far as evidence went, there had never been a flood in the river.
>
> All the canyons and arroyos on both sides of the river were filled with live and dead grass. Whenever it rained, the water was held in these canyons and arroyos and was never allowed to reach the river. …There was indeed no evidence that any rain falling in Arizona ever got out of the territory…"

During the 1870's and 80's the herds of livestock in the area built to large numbers. Some estimates place the number in the Verde Valley and associated side drainages as high as 40 thousand by about 1890 (Munson, 2000). Doubtless for the Upper and Middle Verde watershed as a whole the number was much greater. Cline (1976) reports that cattle numbers escalated rapidly through the 1880's and peaked about 1891. He quotes the Prescott livestock newspaper *Hoof & Horn* in 1888 as warning:

> "Many portions of the Territory are now overstocked to an alarming extent, and the continual driving of stock here places the future pasturage for stock in a very important condition. All available ranges where a natural supply of water can be had are now

> located and settled upon, and those seeking ranges are compelled to either buy or intrude on other parties' property."

Fred Croxen summarized the history of grazing on the Tonto National Forest (primarily the Tonto Creek, Tonto Basin area) in 1926. He said that nearly all the old timers agreed that at the peak of the cattle boom there were 15 to 20 head on the range for every one still present in the 1920's.

Sheep were also raised, with some large herds in the northeast part of the watershed near Flagstaff and the San Francisco Peaks. In the 1800's nearly all of the land was open range and the large areas of public domain, or government land, were used extensively. Cline cites 1887 newspaper estimates of 200 thousand sheep in the area surrounding and including the San Francisco Peaks. Sheep driveways between summer range above the Mogollon Rim and winter range in the Salt River Valley traversed the watershed from south to north and were used regularly until very late in the 20th century. There were also large numbers of sheep in the area near Ash Fork and Seligman. Moore (1986), in describing the history of the Seligman area, reports "some of the old sheep outfits of that day…had more than a hundred thousand sheep."

The natural cycles of drought and floods in the late 1800's had superimposed upon them the most widespread human impacts in recent history, with livestock using (and overusing) virtually all of the available rangeland. Settlers who had moved to the Southwest from more humid environments were generally not prepared for the intensity of the "boom and bust" cycles of precipitation and plant growth. Initially, the area seemed to be a "paradise" for settlement. Willard, in describing his arrival in 1879, said that they,

> "turned the stock loose in the finest pasture to be found anywhere. The grass was knee high and as thick as it could stand."

In describing what subsequently occurred he says,

> "However, almost every settler who came into the country brought cattle and horses, and soon the range was well stocked. These animals would stay in the shade of the trees and graze on the vines. In the evening, they would meander out on to the mesa to graze, returning to the river to drink and enjoy the shade. Generally they traveled single file, and naturally they soon had a trail in the yielding earth.
>
> Besides eating up the grass that had grown for centuries, and tramping into the ground what they did not devour under their feet, the soil became packed so that when the rains came the ground would shed water like rain off a roof. About 1880, the river began cutting on the banks. From that time to the present, it has never quit."

The river through the Verde Valley was often described as slow, frequently impeded by beaver dams, and meandering, with marshy backwaters. There are reports of malaria being a problem due to the mosquitoes (Willard, citations in Whittlesey, 1997). However such a marshy floodplain was apparently not a universal condition. Land surveys in the 1870's, which would have been at one-mile intervals, "did not describe marshy land adjacent to the Verde River, nor did they document any areas where the low-flow channel was ill-defined" (Pearthree, 1996).

After the cattle herds had built up to peak numbers, the effects of dry years began to take their toll. Large numbers of cattle died of starvation. After 1894 cattle numbers were reduced somewhat (Munson, 2000). In addition to cattle and sheep there were large numbers of wild horses and burros.

Plummer (1904) describing conditions in the Black Mesa Forest Reserve discusses grazing, including:

> "As perpetual water is approached the effect of grazing is seen by the gradual, and finally total disappearance of the grasses. Numerous carcasses of cattle and horses testify to their having attempted long trips from water to pasture, but, failing to return in time, perished from thirst…
>
> The Verde slope in the Beaver Creek watershed is an example of repeated overstocking. This district was formerly a source of great wealth to settlers and stockmen in that vicinity, but the excessive number of cattle and horses has finally resulted in the complete annihilation of the pasture…"

In 1890, and again in 1891, major floods struck Arizona. In February, 1891 the lower Verde River experienced peak flows estimated to be among the highest in the last 1,000 years (Ely and Baker, 1985; House, et al, 1995). Reports of flooding were widespread. Included were farm lands along Walnut Creek (tributary to Big Chino Wash) where the floods were "unprecedented". Farmers along the mainstem of the Verde lost "all their ditches and much valuable land and improvements" (Dobyns, 1981). Resurveys of land lines the following year found and recorded new positions of "meanders" of the river in the Camp Verde area and documented several hundred acres of "fine bottomland" being washed away and replaced by channel gravel (Pearthree, 1996). Pearthree reports that the location and size of the flood channel following the 1891 flood has remained essentially the same through the 1993 floods. Floods of note occurred again in 1895, 1903, and 1909 (Byrkit, 2001).

There have been suggestions that human impacts of the late 19th and early 20th centuries actually caused the climate of the Verde Valley to change (Byrkit, 2001), resulting in a drier local atmosphere and greater extremes of temperature. Writing in the mid-1950's Willard (1975) recalled a change in conditions,

> "Old timers will tell you that when they first came to this section, rains were much more plentiful than they are today. It is easy to believe, as I recall having seen grain stacks sprouted all over the top from the constant rainfall."

Willard's contrast of rainfall would have been correct, as the mid-50's were the latter part of the worst drought in 400 years according to tree ring scientists.

Although mining was initiated near Prescott in 1863, its most direct effects on the watershed were from the copper mining and associated smelters of Jerome and Clarkdale on the east side of Mingus Mountain. From the 1870's through the first half of the 20th century the mining activity was an important part of the Verde Valley's economy. In addition to widespread cutting of trees for fueling the smelters in the early decades, the sulphur laden smelter smoke resulted in damage to both native and cultivated vegetation (Beard, 1990, Jerome Sun, 1917). Shrubs and trees appeared to be more affected than were grasses and were reported to be almost completely killed in areas most affected by smelter smoke. A map produced by the mining companies about 1930 displayed an area of vegetation damage from sulfur dioxide running generally north-northwest along the east slope of Mingus Mountain (Beard, 1990). An area labeled as "serious SO2 damage" was approximately 70 to 80 square miles and extended downslope to the Verde River in the Clarkdale-Cottonwood area. An outer area was identified as "trace SO2 damage". It extended upstream along the Verde mainstem to several miles above the confluence of Sycamore Canyon.

In the portion of the watershed above the Mogollon Rim lumbering activities began in the early 1880's, shortly after completion of the railroad to Flagstaff, and quickly became a major part of Flagstaff's economy (Cline, 1976). Areas south and west of Flagstaff in the drainages of Oak Creek and Volunteer Wash (tributary to Sycamore Canyon) were among the earliest within the Verde Watershed to be logged.

1) <u>Vegetative Conditions at Time of European Settlement</u> - Although there is no inventory available of vegetation at the time of European settlement there are a number of accounts both by individual settlers and observers with a technical or scientific background. Leopold (1952) reviewed a number of accounts in the southwestern U.S. He reported a variety of conditions encountered in the mid-19th century, ranging from "..alluvial valleys [which] supported large expanses of grassland" [and in mid-20th century did not] to "..many areas, even alluvial valleys, where grass was so poor that forage for a string of horses could hardly be obtained." In some other areas arroyos and discontinuous gully systems were already present (and by mid-20th century were considerably enlarged).

Shaw (1998) has studied the records of the Whipple expedition across the northern tier of the Verde watershed in January of 1854. This was a military exploratory expedition with daily diaries kept by both the commanding officer, Lieutenant Amiel Weeks Whipple, and some other members of the party. Shaw's analysis included retracing the route and comparing existing conditions to those described in 1854. In addition he consulted some later reports from the 1860's and 70's which overlapped the route, including some landscape photographs from that period. He concluded that the general vegetative pattern in 1854 was much the same as today, albeit there have been some marked increases in tree density in both the ponderosa pine and pinyon-juniper vegetation types and some areas that were interspersed with junipers and openings are predominantly juniper today. However, even then there were areas of dense pinyon-juniper such that the expedition avoided some and the diaries commented on the reduced visibility and difficulty of passage. Specifically some of the areas around Drake and Big Black Mesa could be identified from the descriptions. Shaw reports that he could "see no clear evidence that they [junipers] have greatly extended their range into the larger grasslands, such as Big Chino Valley."

Much has been written about the condition of the ponderosa pine forest at the time of European settlement and the changes which have occurred in the last 125 years. Reports and historical photographs portray a fairly open forest with scattered large trees and grassy understory such that "one could ride a horse at full gallop". In a study on the Bar M Watershed (tributary to Dry Beaver Creek) Covington and Moore (1991) found that trees under presettlement conditions (prior to 1870) constituted only a small fraction of the number in the same area in 1989. Based on sampling, they estimated that there were about 23 trees per acre in presettlement times, mostly in larger diameter classes. (However in 1989 there were approximately 850 trees per acre of primarily small diameter stems [< 4 in.]). Citing several references, they state that establishment of pine seedlings in presettlement times was infrequent due to frequent low intensity fires, competition from bunchgrasses, and climate.

In the ponderosa pine forests fire frequencies of less than 10 years were common in the presettlement times with some as frequent as 2-5 years on the average (Dietrich, 1980; Swetnam, 1990). Near the Mogollon Rim in the Webber Creek drainage of the East Verde (just outside the Middle Verde basin) fire frequencies averaging only two years were found (Kaib, et al, 2000). The degree of fire frequency attributable to humans is not clearly known. Kaib cites several sources, including remote sensing of lightning strikes and records of lightning fires in recent years, plus continued fire regimes in remote areas of Mexico, to conclude that lightning alone was enough to sustain fires at five to ten year intervals.

Leiberg, et al (1904), in describing conditions found in field surveys in 1901 and 1902 described fires in the ponderosa pine,

> "Fires in the yellow-pine belt have marked with basal scars and sears 75 per cent of all the trees having standard dimensions. These sears vary from 6 inches to 12 feet in length and from 3 inches to 2 feet in superficial width…The greatest loss…consists in the destruction of seedlings and sapling trees. Owing to the heavy grass growth which prevails on all areas not sheeped off, surface fires develop considerable heat and flame, and death is certain to all seedling growth in the cotyledon stage…At the same time a good deal of sapling growth, 5 to 15 years old, is sure to be consumed."

He noted damage to more mature forest areas above the ponderosa pine zone,

> "The most extensive and serious of the latest fires…have burned on the southern, western, and northern slopes of San Francisco Peak, covering altogether 18,000 acres. It took place about 100 or 110 years ago [ca 1800], and utterly laid waste a heavily stocked stand of Engelmann spruce and Arizona fir covering about 600 acres. The badly burned areas on which the destruction has been 60 per cent or more aggregate 6,790 acres."

2) 20th Century Uses and Impacts - At about the turn of the 20th century the foundations for modifications in land use were initiated with withdrawal of land from the public domain as Forest Reserves. For example the San Francisco Peaks and Black Mesa Forest Reserve were both withdrawn in 1898 by proclamation of President McKinley. The newly created Forest Service, initially under the Department of Interior but soon transferred to the Department of Agriculture, was assigned the task of managing the use of the Forest Reserves, soon to become National Forests. Early Rangers were mostly local men with practical experience in ranching or lumbering hired to fight the fires, enforce the regulations, and make forest products available for appropriate use by the local settlers. They worked under the supervision of a cadre of college trained foresters.

One of the first tasks was to make timber on government land available through sale and do it in an organized and regulated manner. Another major early task was establishment of grazing permits for livestock grazing, generally based on historic and existing area use.

Groups of livestock owners grazing a general area in common continued until the early 1920's when assignment of allotments to individual ranches, and development of fences to separate allotments began. The open-range situation was gradually eliminated, though individual allotments might still be many miles across.

Fighting fire was a priority. The natural fires which had occurred so frequently prior to settlement had already been greatly reduced as a result of extensive livestock grazing which eliminated most of the grasses which had previously carried low intensity fires on a regular basis. Local ranchers and settlers were hired on the spot to assist in fighting fires.

Ponderosa pine requires specific conditions to establish seedlings and optimum conditions occur rather infrequently. Following the turn of the 20th century periodic climatic conditions were aided by livestock grazing which reduced competition from grasses and helped provide mineral soil seedbeds for pine seeds to utilize. Fire suppression then assisted in obtaining survival of seedlings. One of the most notable regeneration periods occurred about 1919 and the succeeding few years. The unusually high germination and survival of this 1919 seed crop followed by the continued aggressive fire suppression program led to hundreds of thousands of acres with dense stands of pine trees of this age. Periodic spurts of seedling recruitment have occurred in the succeeding 80 years but not of the same areal magnitude.

The Civilian Conservation Corps (CCC's) of the 1930's provided an investment in land improvements in unprecedented degree. Thousands of miles of fence and hundreds of water developments added to the ability to manage livestock on the grazing allotments. Check dams were constructed in gullies, access roads and trails were built, campgrounds and other recreation areas were built – often in riparian areas. Following World War II management of the National Forests was intensified. Road networks were improved so that more area could be subject to timber harvest and management. Programs of thinning and tree planting were emphasized. Range management was intensified with a greater amount of ecological data collected as a basis for evaluating rangeland condition and trend. In addition to the structural improvements of fences, water developments and livestock handling facilities, vegetation treatments were added. Chief among these was treatment of pinyon-juniper areas. The objective was to remove or greatly reduce the number of pinyon and juniper trees and allow grass, forbs and shrubs to occupy the sites. Tens of thousands of acres were treated by chaining, cabling, or individual tree pushing.

As the mid-century drought continued into the mid – 1950's, concerns over the reduced water supply and low reservoir levels were combined with the feeling by some that the increased density of trees and shrubs throughout the state's watersheds was further reducing the water which might otherwise be available for thirsty cities, towns, and agricultural fields. In 1956 the Barr Report was issued by the University of Arizona. Dr. George W. Barr, an agricultural economist, chaired the effort to evaluate what could be done to increase water yield from the watersheds. Primary cooperators included the Salt River Project and the Arizona State Land Department – Water Division (at that time management of water rights and water planning was under this department. It was a number of years before the Department of Water Resources was established.) Technical contributors included several Forest Service researchers and university faculty in the relatively young field of watershed management. As might be expected, analysis was concentrated on the Salt and Verde watersheds, providers of the water supply for Phoenix and surrounding area.

The Barr Report analyzed available precipitation and runoff data from the Salt and Verde watersheds for 40 years of records – water years 1914 through 1953. The authors determined that 1914-1930 was wetter than the 40 year average while 1931-1953 was dryer. They also concluded that a lesser percent of precipitation was being captured as runoff than had occurred in the early part of the century, though acknowledging that there was not necessarily a linear relationship and that as precipitation declined a smaller proportion would be runoff. Several of the outside specialists submitted individual analyses of potential for water yield increases. At the low range was an estimated increase of 100 thousand acre-feet per year (average), or about ten percent, from treating 578 thousand acres of the two watersheds. At the high end was an estimate of 180 thousand acre-feet increase from treating 1.25 million acres of the watersheds – the higher priority areas, but suggested that an additional 112 thousand acre-feet increase could be obtained by treating an additional 6.67 million acres of lower priority area.

Evaluations and recommendations in the Barr Report reflected the utilitarian values of that timeframe. For example, one of the highest priority recommendations was to eliminate riparian vegetation over significant portions of the primary streamcourses. Methods suggested include,

> "…aerial poisoning of solid blocks of riparian vegetation such as the salt cedar and mesquite; the deepening of channels to lower ground-water levels adjacent to the streams; and the poisoning of individual larger trees such as cottonwoods and sycamores."

Another contributor pointed out the need to classify stream channels as to their value and need for,

> "…present recreational uses, and most certainly anticipated recreational needs for a long time to come. With a liberal allowance for all these uses, it is quite likely that 70 to 80 percent of the present riparian vegetation in wet and dry channels could be classified as of little value, and therefore subject to removal either by killing with defoliating sprays, or by other economical means."

One author referred to ponderosa pine growing in more moist areas as having a tendency to "water piracy".

There was considerable variation in interpretations and recommendations among the specialists and a number of cautions and qualifications were given. In general they gave a lower priority to the chaparral vegetation type and were not optimistic about opportunities in the pinyon-juniper. In discussing heavy commercial cutting and reduction of understory to proper stocking in ponderosa pine P.B. Rowe said,

> " Such a treatment could…be justified as good forestry practice. …reduction of present density …would result in a reduction of interception loss and a slight increase in water yield. Likewise, the first year or so following cutting there may be a reduction in evapotranspiration rates that could result in a slight increase in yield during periods of percolation. The opening up of the stand may result in more rapid melting of snow and thus an increased yield from this source. It is questionable, however, that any of the

above sources would result in appreciable increases in stream flow (Q) over long periods of time."

The Barr Report was a very early part of what became the Arizona Watershed Program. Over the next 25 years several million dollars were spent in watershed research and a substantial amount in land treatments with one of the primary purposes being increased water yield (Baker, 1999). A major part of the research was in the Verde Watershed in the Beaver Creek Watershed of the Coconino National Forest. Started in 1957 by the Coconino National Forest, the research and data collection effort was soon taken over by the Rocky Mountain Forest & Range Experiment Station, while implementation of research land treatment prescriptions was continued by the Forest. Major data collection activities continued through the 1981 water year and analysis is still continuing. An annotated bibliography prepared in 1999 lists some 683 literature citations resulting directly and indirectly from the project area (Baker and Ffolliott, 1998). A summary description and numerous data tables are available through a University of Arizona web site:

http://ag.arizona.edu/OALS/watershed/beaver/

Although the Forest Service did not agree to remove riparian vegetation, other parties felt the urgency of implementing the proposals. The Salt River Project engaged in a program of riparian tree removal on private land where they could obtain permission. Explaining that these trees used large amounts of water at a time when the area had been suffering from a prolonged drought, they often persuaded landowners to allow them to remove cottonwoods and other trees along the mainstem of the Verde River in the Verde Valley.

Annual reports and updates on the research and implementation programs were given at the Arizona Watershed Symposium each year. In 1974 a major emphasis was on summarizing what had been learned to date, e.g., Ffolliott and Thorud, 1974. Reports in subsequent years after more time had passed since treatments were not as optimistic as immediately after treatment. A series of three consecutive very wet winters, beginning in 1978, created runoff which greatly exceeded the storage capacity of both the Salt and Verde River systems and caused flooding of most Salt River street and highway crossings in Phoenix. (The current storage capacity created by the Central Arizona Project by expansion of Roosevelt Lake was not yet available.) With the most recent water problems being flooding and not enough storage capacity, it became more difficult to generate public support for programs to increase water yield through vegetation management.

a) Timber management - Management intensities and investments on National Forests increased during the 1960's, continuing through the 1970's and 80's. In the early 1960's the Forest Service entered into a 30-year contract for the sale of pulpwood on the Colorado Plateau. Southwest Forest Industries built a pulp and paper mill near Snowflake. This provided a market for small diameter pine trees (5-10 inches diameter measured 4.5 feet above the ground) and a feasible means of thinning some of the dense stands of understory ponderosa pine which had become started since the effects of European settlement. The sale area extended westward through the Long Valley Ranger District of the Coconino National Forest or some of the southeastern part of the Middle

Verde watershed. Through the late 1970’s and 80’s some pulpwood was also sold from portions of the Coconino National Forest north and west of the Colorado Plateau Pulpwood Sale area. By the time the sale ended in the early 1990’s, changing market conditions and increased costs for air and water pollution control equipment resulted in most of the mill’s input being newsprint and other recycled paper products. Today the mill takes virtually no raw wood and this opportunity for economical thinning of smaller diameter trees is no longer available.

The Resource Planning Act of 1974 called for the Forest Service to identify and eliminate backlogs of needed thinning and reforestation. For a number of years significant funding was available for precommercial thinning (thinning in tree sizes too small to be sold as pulpwood).

In the mid – 1980’s each National Forest was preparing a Land and Resource Management Plan as required by law to guide management for the following 10-15 years. A substantial part of the effort on the Coconino and Kaibab National Forests was the timber management program. Guidance on timber harvest, thinning, old-growth and snags to be retained, wildlife cover to be maintained, etc. was described in detail. A major change from previous practice was heavy emphasis on achieving even-age management, i.e., the majority of the trees in a stand of 10-100 acres being of about the same age and size. Oftentimes this meant removing nearly all of the old “yellow pines” which had survived since presettlement times and keeping the much more numerous younger trees, following their thinning to a more suitable density. The large, old trees were to be kept primarily in specific areas designated as “old-growth”.

One of the most debated components of the Forest Plans was the allowable sale quantity, or the amount of timber each Forest could sell over the next 10 years. Sawmills within or near the Verde Watershed at that time were located at Flagstaff, Williams and Payson. In addition, a mill at Winslow sometimes purchased timber sales within the watershed and a mill at Heber often competed with the Payson and Winslow mills for sales just outside the watershed.

In the late 1980’s the Forests began to implement their management plans. At the time the plans were prepared there was only a small amount of knowledge about the presence and habitat requirements of the Mexican spotted owl and the northern goshawk. Within a few years the owl was formally listed under the Endangered Species Act by the U.S. Fish and Wildlife Service (USF&WS) and the goshawk was considered a candidate species (the USF&WS was petitioned to list the goshawk and later sued because they did not.) Surveys discovered many more Mexican spotted owls and northern goshawks than were expected. Habitat requirements recommended by wildlife biologists and concurred in by the USF&WS meant that large acreages had to remain in high density forests with most of the older & larger trees left intact. As a result, significant portions of the area anticipated for timber harvest and intensive management were eliminated from planned timber sales and continued to slowly increase in density.

During the 1990’s the majority of sawmills in northern Arizona closed, including all those in or adjacent to the watershed. A combination of economic and financial factors, along with the reduced timber available for sale, was given as the reason. Today there are no major sawmills in or near the watershed.

b) Fire and fuels management – Since the inception of the Forest Service, forest fires had been considered as a threat to be prevented or suppressed at all costs. The period of 1905 to 1930 was wetter than the long term historic average on the Verde watershed . However, during this same time period and into the early 1930's there were some large and quite devastating fires in the northern Rocky Mountains and the Pacific Northwest, which led to further Forest Service emphasis on fire suppression. Policies of keeping fires within 10 acres and planning to control fires by 10 am of the morning following detection were applied throughout the west.

During most of the 1930's the CCC camps provided a ready supply for manpower – already working in the woods – for fire suppression. Forest areas which formerly burned over lightly every 2-7 years on the average went decades without fire. Ponderosa pine needles do not decay and become incorporated as organic matter in the soil as rapidly as they accumulate. Thus there was an accumulation of needles and dead twigs on the forest floor, especially under the crown (branches) of the larger old trees where, along with shed bark scales, depths of 8-10 inches or more might accumulate adjacent to the tree trunk. Groups of pine seedlings which had become established had not been subjected to the thinning and removal effect of frequent fires. Dense thickets with flammable needles reaching from near the ground to six or more feet on younger trees were often adjacent to slightly larger trees with needle clad branches reaching down to a few feet above ground level. The result was a situation termed "ladder fuels" where flames can quickly climb upward to the crowns of large trees and spread rapidly, burning all the needles and generating enough heat to kill even the largest trees.

Improvements in technology and operations helped to keep most fires very small and prevent them from reaching large size. Lookouts, aerial attack with retardants, readily mobile small bulldozers for building fireline, strategically placed engines carrying water, and highly trained "hot-shot" fire crews all provided means of suppressing fires before they reached large size. However, under the most severe conditions of low fuel moisture, low relative humidity, high temperatures and high winds which occur in some years fires spread very rapidly and may reach a size where they escape the initial attack forces and burn hundreds or thousands of acres before finally being suppressed. These fires are generally quite damaging, killing both understory and overstory vegetation, and oftentimes resulting in sealing of the soil surface for the first season or two. Increased runoff from summer thunderstorms and soil erosion occurs, especially where there are steep slopes. Lost topsoil results in reduced productivity and sometimes requires many decades before the site is recovered to the same degree of stability and productivity. Evaluation of effects of the 1972 Rattle Fire within the Oak Creek watershed found that erosion from severe burned areas was two to three orders of magnitude larger than from unburned areas in the first two years (Campbell, et al 1977).

Timber sales contracts called for reducing the fire hazard created by slash (unused limbs, tops, rotten logs, etc.) to no greater than was present before the sale. The usual procedure was piling the slash and debris with bulldozers and burning the piles in the winter when the danger of spread was minimal. Commonly this piling with bulldozers resulted in also piling natural fuels which had accumulated as a result of fire suppression. The result was a temporary reduction in fuels and fire danger in the portion of the timber sales treated in this manner.

During the drought of the 1950's there were some calls from university professionals in range management, as well as some from the livestock community, for fires to be used, especially in "low value" vegetation types such as pinyon-juniper and chaparral. In 1956 a fire started on private land to improve range conditions escaped and burned many thousands of acres on the Prescott National Forest, including some areas of ponderosa pine within the Verde watershed. The subsequent rhetoric on both sides of the issue resulted in polarization and may have contributed to delay on the part of the Forest Service in actively pursuing a prescribed burning program in Arizona.

During the 1970's the Forest Service began a modest program of prescribed burning in the ponderosa pine. Fires were started under prescribed conditions that reduced the likelihood of escape or rapid spread. The time of year most used was the fall. However, areas within the Verde watershed are often subject to downslope winds in the evenings and inversions in the valleys, resulting in smoke reaching populated areas of the Verde Valley. Air quality concerns and subsequent more stringent regulation of smoke emissions by the Arizona Department of Environmental Quality limit the amount of area that can be burned. The program continues today.

Recognizing the effects of many decades of fire suppression and public concerns with even age management that removed most of the largest older trees and emphasized obtaining growth on the younger trees, staff from Northern Arizona University (NAU) initiated a research program to evaluate presettlement conditions and apply the lessons learned to modern forests. The Ecological Restoration Institute at NAU has a number of research projects and several field demonstration projects in cooperation with the Forest Service and the Bureau of Land Management. The projects on and near the Fort Valley Experimental Forest near Flagstaff are just outside the Verde watershed and represent similar conditions to thousands of acres within it. The treatments involve identification of presettlement tree patterns and densities and managing to replicate or partially replicate those conditions.

The urban interface or edge between wildland forest and developed residential areas has become an area of high emphasis for fuels management. Combinations of mechanical thinning, piling and burning of slash and followup maintenance are being developed, especially around the community of Flagstaff. The Forest Service and the Flagstaff Fire Department have jointly developed programs to treat lands on National Forest and private lands, respectively, in a coordinated approach. A consortium of citizens groups has formed an organization supporting an integrated management approach to reducing fuels and maintaining ecosystem health in an area north and northwest of Flagstaff. Their proposals to work with public land managers draw upon lessons and examples from the Ecological Research Institute.

c) Range Management – As mentioned previously, management of rangelands gradually became more intensive. Beginning in the 1930's the Soil Conservation Service (now the Natural Resources Conservation Service) provided technical assistance for private land owners upon request and local Soil Conservation Districts (now Natural Resource Conservation Districts – NRCD's) provided a means for participation and leadership by local landowners interested in conservation practices. Following World War II, and continuing to the present, federal cost sharing programs assisted in installation of certain improvements for range management including some water developments and erosion control features. Assistance varied from technical assistance and engineering to actual reimbursement for a portion of the costs incurred.

Under the Arizona state constitution state trust lands are to be used to generate maximum revenue for certain designated educational and institutional beneficiaries. Their location within the watershed is generally intermingled with private land in Big Chino Valley and with National Forest land in the Verde Valley and above the Mogollon Rim south of Rogers Lake. Grazing leases are issued for a maximum 10 year term. Lessees are encouraged to work with local NRCD's and incorporate grazing management on State Trust land with the intermingled private or public land on which they also graze livestock.

At the time the National Forests were established around the turn of the 20th century and into the first two decades, it was widely recognized that the ranges had been greatly overstocked in the 1880's and 1890's resulting in damage to both the vegetation and soil. In addition to breaking up the open range into smaller portions and eventually fencing individual grazing allotments, emphasis was placed on reducing livestock numbers. This was usually done somewhat gradually unless the rancher was willing to reduce numbers. For a period of time there was an automatic ten percent reduction when the permit changed hands, i.e., from one rancher to another. During World War I, and again in World War II, there was a national call to produce food and fiber – red meat and wool – from public lands and many reductions were halted or reversed. Achieving what was judged to be proper stocking was to take decades and was affected by the compounding effects of the mid-century drought.

During the 1930's the CCC's were used to accomplish many range and range related improvements. The research arm of the Forest Service expanded its role and more studies were conducted. A common approach was construction of small – ½ to a few acres – fenced exclosures to compare the effects of livestock grazing with protection from grazing. On some there was a quick response and the visual comparison was striking. However, on many exclosures in the pinyon-juniper and semi-desert shrub/grassland vegetation types there was little visual contrast, even after several decades of exclusion of livestock. The most common study was the Parker three step range transect, permanently installed line transects where the presence or absence of vegetation and its specific identification were measured at 300 individual points and then remeasured at periodic intervals to identify trends in range conditions. In later decades this methodology would come under criticism for its statistical validity; however, because of the large amount of historical data, it is still used as one component of long term range monitoring.

More intensive management of livestock through smaller pastures and more closely spaced waters was emphasized. Various applications of principles of rest-rotation grazing, deferred-rotation grazing, etc. were implemented. The objectives were to consider the impacts of grazing on plant physiology and to allow enough rest at appropriate times for desired plants to maintain root reserves, establish new plants, and provide soil surface protection from raindrop impact and soil erosion, while still harvesting forage. In the late 1980's a new system – "Holistic Resource Management" – was introduced and implemented on a few ranches. This involves goal setting, detailed planning, intensive monitoring, adjusting, and replanning. It has often included more and smaller pastures, as well as shorter periods of grazing in individual pastures. On the Prescott National Forest this system was implemented on the West Bear-Del Rio allotment which includes a number of miles of the Verde River below Paulden. It was also implemented on a portion of the Yavapai Ranch west of Big Chino Valley in an area of checkerboard pattern of private land and Prescott National Forest.

d) Urbanization – Though affecting only a very small areal percentage of the watershed, urbanization has localized major effects on watershed condition and hydrologic function. Population figures from censuses from 1970 through 2000 are displayed in Table 2. Incorporated communities are listed as well as unincorporated areas with enough population to be recognized as "census designated places" (CDP's). As outlying areas have become developed for residential use they have been added as CDP's. For example in the 2000 census CDP's were added for Parks, Paulden, and Williamson (Valley). Figure 2 illustrates the growth of Yavapai County from 1950 to 2000. For comparison, Prescott and Flagstaff are also displayed. Of note is the growth of Yavapai County, increasing more than fourfold between 1970 and 2000.

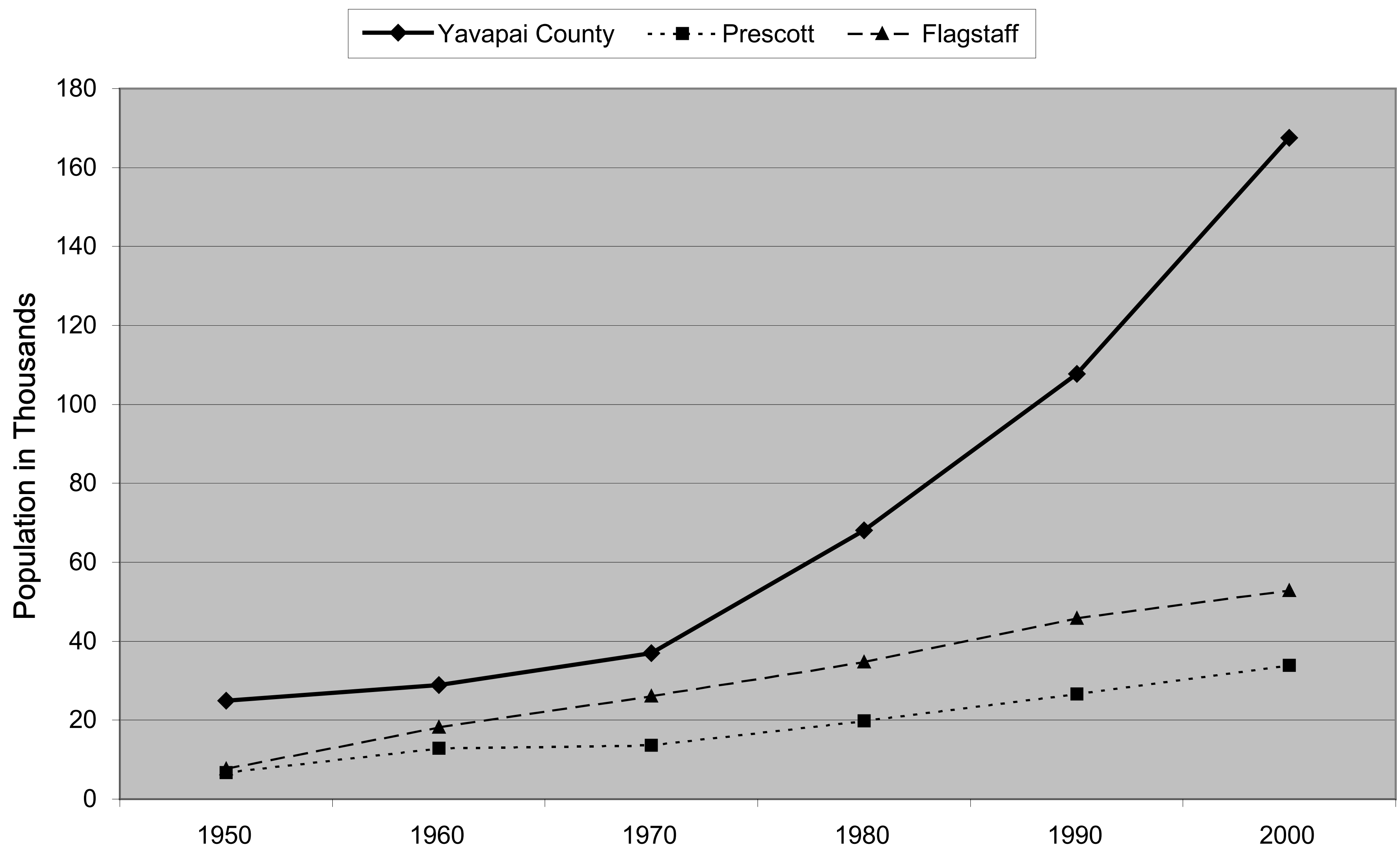
The Arizona Department of Economic Security makes long range forecasts of population. The most recent forecasts were done in 1997 and are displayed for the communities for which they were done. These are shown in Table 4 alongside the actual census results.

Of significance to watershed condition and function is the large amount of urbanization which has occurred and is continuing to occur along and adjacent to the stream corridors in the Verde Valley – the Verde River, Oak Creek, and lower Beaver and West Clear Creeks. Many properties which were originally homesteaded for farming purposes are gradually being converted to various densities of residential use.

e) Transportation and Recreation - With the rapidly expanding population, both in the watershed and the Phoenix metropolitan area, recreation on the public lands has expanded almost exponentially. In addition to the highways and roads necessary to serve communities and outlying ranches and residential areas, there are literally thousands of miles of relatively low standard roads on the National Forests. Many of these have been developed through use, as over much of the area the topography and vegetation do not physically preclude vehicle use. Initially they may be rather benign, a set of tracks across the grass or understory vegetation. However, their visibility invites others to follow. Use during wet periods leads to ruts which, on slopes, leads to erosion and sediment production. In some areas several multiple parallel "roads" have developed through

TABLE 4. POPULATION FROM 1970 TO 2000 CENSUSES PLUS 1997 PROJECTIONS BY AZ DEPT. OF ECONOMIC SECURITY													
YEAR	**1970**	**1980**	**1990**	1997	2000	**2000**	Percent	2005	2010	2015	2020	2025	2030
	Cens	**Cens**	**Cens**	Proj	Proj	**Cens**	Difference	Proj	Proj	Proj	Proj	Proj	Proj
Ash Fork				464	472	**457**	(3.2)	486	499	512	525	537	547
Big Park CDP			**2,995**	4,134	4,614	**5,245**	13.7	5,453	6,317	7,175	8,007	8,775	9,443
Camp Verde		**3,824**	**6,243**	7,999	8,742	**9,451**	8.1	10,051	11,407	12,759	14,068	15,272	16,318
Clarkdale	**892**	**1,512**	**2,144**	2,776	3,040	**3,422**	12.6	3,488	3,932	4,363	4,786	5,181	5,531
Cornville CDP				2,783	3,083	**3,335**	8.2	3,607	4,147	4,683	5,203	5,683	6,101
Cottonwood	**2,610**	**4,550**	**5,918**	6,794	7,167	**9,179**	28.1	8,456	10,749	13,033	15,246	17,283	19,053
Cottonwood-Verde Village CDP			**7,037**	9,089	9,977	**10,610**	6.3	10,905	10,905	10,905	10,905	10,905	10,905
Jerome	**290**	**420**	**403**	569	596	**329**	(44.8)	641	686	729	772	812	847
Kachina Village CDP				2,074	2,215	**2,664**	20.3	2,451	2,683	2,910	3,120	3,321	3,522
Lake Montezuma CDP				2,257	2,437	**3,344**	37.2	2,752	3,076	3,398	3,710	3,998	4,249
Mountainaire CDP				865	915	**1,014**	10.8	981	1,046	1,125	1,199	1,269	1,340
Oak Creek Canyon NPP				320	330			344	358	375	391	406	421
Munds Park CDP				797	924	**1,250**	35.3	1,094	1,260	1,465	1,654	1,834	2,015
Sedona	**2,022**	**5,319**	**7,720**	9,446	10,099	**10,192**	0.9	11,230	12,380	13,521	14,611	15,626	16,546
Seligman				514	521	**456**	(12.5)	532	543	554	565	575	583
SUBTOTAL*				50,881	55,132	**60,948**	10.5	62,471	69,988	77,507	84,762	91,477	97,421
ADDED IN 2000 CENSUS													
Parks CDP						**1,137**							
Paulden CDP						**3,420**							
Williamson CDP						**3,776**							
Total Outside Prescott AMA*					55,132	**69,281**							
Chino Valley	**803**	**2,858**	**4,837**	6,950	7,810	**7,835**		9,184	10,445	11,602	12,771	13,900	14,928
Prescott	**13,631**	**19,865**	**26,592**	32,037	34,366	**33,938**		38,329	42,272	46,104	49,863	53,376	56,472
TOTAL WATERSHED*				89,868	152,440	**111,054**		109,984	122,705	135,213	147,396	158,753	168,821
* Includes Incorporated communites and Census Designated Places (CDP). Does not include some rural areas with widely dispersed residents.													
Note: Columns in bold are actual census results. Other columns are population projections made in 1997.													
Percent difference is difference between 2000 census and projections for 2000 made in 1997.													

Figure 2. Population Growth 1950-2000



specific segments as each becomes rutted and then washed out to underlying rocks left behind. Within the five small sample watersheds evaluated in this study (page 29) which are not urbanized road density averaged 2.3 miles per square mile in the ponderosa pine and 1.4 miles per square mile in the pinyon-juniper, chaparral, and desert shrub. This total included all standards of road, ranging from paved highways to low standard four-wheel roads with minimal maintenance.

Off-highway vehicle travel has greatly accelerated in the last 20 years. Although they commonly have less bearing weight, i.e., the weight is distributed so that there is less tendency to create ruts, use on steep hillsides or wet meadows has created localized erosion and sediment problems.

f) Water Management Structures – No discussion of impacts on watershed functions would be complete without discussion of water management structures, primarily dams and ditches.

Although there are no dams on the mainstem of the Verde River after it becomes a perennial stream until Horseshoe Reservoir in the Lower Verde, it is affected by impoundments on tributaries, most relatively small. The largest are Watson and Willow Valley Lakes, located within the Prescott Active Management Area, but still tributary to the Verde via Granite Creek. Built by the Chino Valley Irrigation District, they were recently purchased by the City of Prescott for use in their long term water management portfolio.

Sullivan Lake, located on the Big Chino Wash just upstream from the incised canyon where the Verde becomes perennial, was built in the 1930's. One of its purposes was reported to be to halt incipient channel headcutting and entrenchment from moving up the Big Chino and lowering the base level for a potentially large area (Foster, 2000). It drains a large proportion of the watershed above the Paulden gage. Originally providing a recreational lake, it filled with sediment in a relatively short period of time and now has very limited capacity.

The Arizona Department of Water Resources (2000) reported on a 1996 inventory that identified 2,635 impoundments in the Upper and Middle Verde watershed (including that portion within the Prescott AMA). Size ranged from 0.1 to 350 surface acres and an estimated 2,030 were less than 1.5 surface acres. The majority of these were constructed to provide livestock (and usually wildlife) water. Usually they are on relatively small watersheds of a few tens to a few hundred acres. Most have a capacity of 1-5 acre feet. Within the five small sample watersheds evaluated in this study which are not urbanized approximately 29 percent of the watershed area was upstream from a stock tank.

The cumulative effect of stock tanks on water yield from the watershed has been a subject of debate. Proponents believe that much of the water they catch from summer monsoon storms would not have reached reservoirs and that seepage losses may at least partially return to the system. Opponents cite the very large number and cumulative capacity. In addition they assert that, at the very least, evaporation from the tanks is a net loss to the system and question the efficacy of seepage returning to the usable system.

One effect of all of the impoundments is to interrupt the movement of sediment down streamcourses. Again, there is not agreement on the overall sediment situation. Some, (e.g., Medina) believe that streambank and terrace building on the mainstem of the Verde has been slowed from natural conditions due to this entrapment of sediment in the many impoundments. Others believe that this entrapment has been at least partially offset by increased sediment from other sources, e.g., the many low standard roads, OHV use, soil disturbance from livestock grazing, mining quarries near ephemeral drainages, etc.

Diversions and ditches are located both in the Upper and Middle Verde watersheds. In the upper watershed diversions are located along Walnut Creek, Apache Creek and Williamson Valley. The majority of diversions are located in the Verde Valley on the mainstem of the Verde and its tributaries of Oak Creek, Beaver Creek, and West Clear Creek. The majority of the ditches originated in the 19th century. Reporting on behalf of Salt River Valley interests, engineer O.A. Turney (1901) listed more than 75 ditches from the Verde and its tributaries. The Arizona Department of Water Resources Verde River Watershed Study (April 2000) includes a quite detailed inventory of ditch systems. The magnitude of diversions is such that the flow in the Verde River is reduced by 2/3 or more downstream from the Cottonwood Ditch (and was reduced to only a trickle for a few hundred yards downstream for a period during the summer of 2001). Unused water or “tail water” eventually returns to the river; however, the majority of the ditches are unlined so that large amounts are lost to seepage, resulting in redistribution of surface water to generally shallow groundwater.

III. CURRENT CONDITIONS

Following the discussion of historic uses and conditions the relevant question is "What is the current condition of the watershed?" The context for this analysis is the effect of soil and vegetation conditions and human influences on the hydrologic cycle.

A. Methodology and Process

The majority of the watershed is in public ownership and currently less than two percent is urbanized or in intensive agriculture. The procedure available for federal land management agencies was reviewed, "A Framework for Analyzing the Hydrologic Condition of Watersheds"[1]. This process focuses on water flow, quality and timing. It characterizes the effects of natural factors – e.g., precipitation, geology, topography, vegetation, soils –on water flow, quality, and timing. It describes the effect of human influences – e.g., livestock grazing, roads, mining, groundwater extraction, urbanization, etc. -- on water flow, quality, and timing. It then attempts to quantify current (the last 10 years) and "reference" levels for components. Reference levels are defined as "…the conditions that would be expected if the system were operating without significant human influence." Components and their range of variability are determined for current conditions. For water flow they might include water yield in acre-feet, annual peak flow in cubic feet per second (cfs), minimum 7-day flow in cfs, etc. For water quality, parameters such as total dissolved solids in milligrams per liter (mg/l), suspended sediment in tons, and nutrient concentrations in mg/l might be evaluated. Reference conditions are estimated from historic records or journals, models or simulations, extrapolations, and records or studies of other areas or least disturbed areas or, where possible, by assuming removal of the human influence..

For this analysis the approach of comparison of current conditions to "reference conditions" was used. However, it was more limited because of the size of geographic area and the fact that some parameters are being evaluated separately. The effect of groundwater extraction on water flow is a part of USGS ongoing studies. The Arizona Department of Environmental Quality has a current project to evaluate nutrients and turbidity in the Verde River.

Current conditions can be analyzed from several standpoints. First, is the evaluation by land management agencies for public and Arizona state trust lands. The methodology and consistency of these evaluations is variable. The largest individual land holder, the U.S. Forest Service, is divided among three different National Forests, each having a portion of the watershed. The most common evaluations are based on "soil condition", a part of Terrestrial Ecosystem Surveys (TES). Development of procedures and interpretations for rating soil condition has been, and continues to be, an evolutionary process. Thus, a survey being done today has significantly different criteria for consideration than does one done 15 years ago.

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[1] "A Framework for Analyzing the Hydrologic Condition of Watersheds. June, 1998. USDA Forest Service and USDI Bureau of Land Management. BLM Technical Note 405.

Another evaluation tool used for watershed condition was modeling the effects of current and natural -- i.e., climax -- conditions on soil infiltration, and thus storm runoff. The Curve Number (CN) methodology, pioneered by the USDA Soil Conservation Service (now the Natural Resource Conservation Service) was used for comparative evaluation (USDA, 1972). CN is dimensionless and may be seen as a measure of the site's hydrologic condition, affected by soils, cover, and land use. Curve Numbers may vary from a low of 0 to a high of 100. Tables and graphs of CN as a function of soils and cover for a variety of land conditions are given in agency documents, and the method is widely used for hydrologic design, environmental impact evaluation, and post-event appraisals.

Besides looking at broad area summaries and statistics, a smaller sampling system was used. Several small subwatersheds were selected for more detailed analysis. Size was approximately three to eight square miles. Selection criteria included representing the spectrum of geology, vegetation types, and land uses. The availability of existing inventory and or analysis information was also used as a selection criteria. Figure 3 illustrates the location of sample watersheds. Table 5 summarizes their conditions. More detailed information and descriptions are included in the appendix. Field visits were made to each to review both upland and channel conditions, and compare upland cover descriptions to that given in TES reports. Where field review suggested conditions might be significantly different for a TES unit within the sample subwatershed from its forest average, transects of 300-500 points were made for ground cover using end points on quadrat frames as described in Guidelines for Monitoring Arizona Rangelands (Ruyle, et al 1999). Relevant inventories, studies, and management plans affecting the sample subwatersheds were also reviewed.

TABLE 5. SAMPLE SUBWATERSHEDS

Name	Size sq mi	Geology	Vegetation	Ownership	Comments
Witty Tom	6	basalt, sedimentaries	pinyon-juniper	Prescott National Forest	Drains direct to Verde River
Sawmill	4.8	granite, schist	chaparral, pinyon-juniper	Prescott National Forest	Drains to Williamson Valley, Big Chino
Sheepshead	6	limestone, alluvium (Verde Formation)	desert shrub & grassland, juniper	Arizona State Trust, Coconino National Forest	Drains to Oak Creek. Springs & diversion in lower segment.
Cougar Park	7.7	basalt	ponderosa pine	Kaibab National Forest	Drains to Hell Canyon
Watershed 8	3	basalt	ponderosa pine	Coconino National Forest	Within Beaver Creek Experimental Watersheds
Big Park (2 adjacent)	3 & 2.8	Paleozoic sediments	Pinyon-juniper and desert shrub	Private with some Coconino Nat For	Urbanization and golf courses within the watersheds

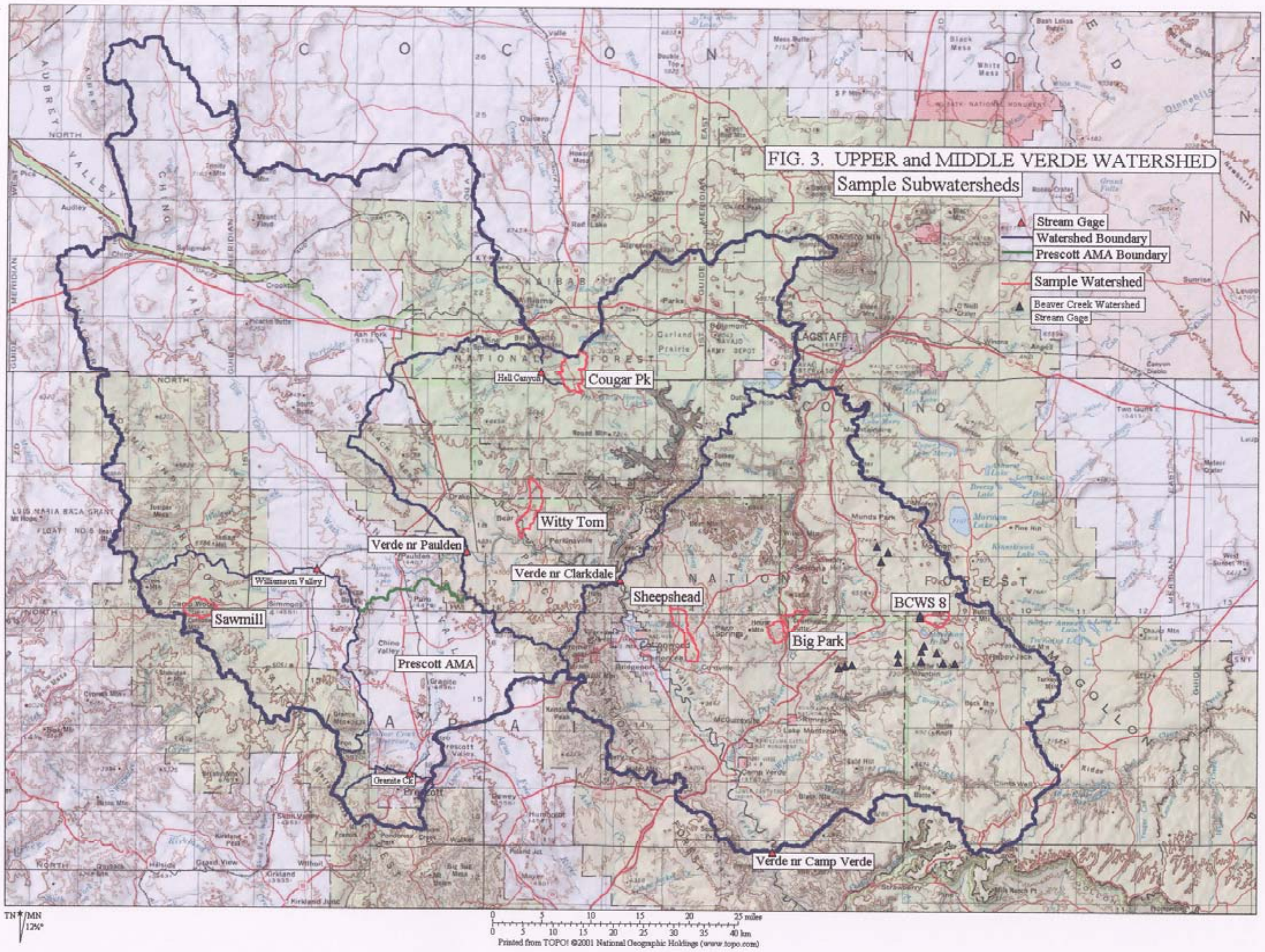
FIG. 3. UPPER and MIDDLE VERDE WATERSHED
Sample Subwatersheds
Stream Gage
Watershed Boundary
Prescott AMA Boundary
Sample Watershed
Beaver Creek Watershed
Stream Gage
Hell Canyon
Cougar Pk
Witty Tom
Verde nr Paulden
Verde nr Clarkdale
Williamson Valley
Sheepshead
BCWS 8
Sawmill
Big Park
Prescott AMA
Granite Cr
Verde nr Camp Verde
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In addition to the sample subwatersheds, general field review was made of other portions of the watershed. For example, a field review and review of historic range transect data was made for a part of the Partridge Creek area in the northwest part of the watershed.

Information on watershed condition on lands outside the National Forests was not available. The Natural Resource Conservation Service had some limited information on range condition on a few ranches containing both Arizona State Trust and private land. However, that information was not specific to watershed condition, and the information on the private land portion was considered to not be public information. One of the sample subwatersheds contained a significant block of Arizona State Trust land and written permission was obtained to enter it for the purposes of the study.

B. Analysis Based on Soils and Vegetation Information

As displayed in Table 1, National Forest land makes up 63 percent of the watershed area. Terrestrial Ecosystem Surveys (TES) are available for each of the three National Forests included. Status of the different surveys is as follows:

Kaibab National Forest. Field work was done from 1979 to 1986 and the report was completed in 1989. Soil condition was not addressed specifically. However, some of the components used for condition were incorporated. These include existing soil cover components of rock fragments, vegetative basal area, litter, and bare soil expressed as percentages of the area. Estimates of sheet and rill erosion rates using the Universal Soil Loss Equation were made for four conditions, 1) existing, 2) natural, i.e., under undisturbed climax conditions, 3) potential (maximum erosion) with no vegetative or litter cover, and 4) the tolerance, or maximum amount which can occur while sustaining inherent site productivity. (For each of the three National Forests the "natural" condition is for the vegetative climax possible with the existing soil profile. It is not necessarily presettlement conditions, i.e., if a soil has been impacted by losing a significant part of its A horizon the cover density given for natural condition are for that soil as impacted if it were under its potential vegetative climax [Robertson, 2001]).

Coconino National Forest. Field work was done from 1987 to 1991. In addition to the information in the Kaibab National Forest TES, overstory canopy density is given. The current components of soil cover are supplemented with projected components under “natural” or climax conditions. Soils are rated as in Satisfactory, Unsatisfactory, or Unsuited Condition. If the calculated existing soil loss rate is less than the tolerance level it is classified as Satisfactory. If it is greater than the tolerance level the rating is Unsatisfactory. In cases where the calculated natural rate exceeds the tolerance rate it is classed as Unsuited. More recently, this has been changed to “Satisfactory/Inherently Unstable” to reflect the situation due to geological conditions and the need to manage accordingly. In addition, a few units have been reclassified from Satisfactory to Impaired.

Prescott National Forest. Field work was done from 1992 to 1997. By this time there had been some evolutionary changes in soil condition as defined in the TES report:

> “**Soil Condition** - Soil condition ratings apply to lands where long-term soil productivity and

satisfactory watershed condition are the primary objectives. Soil condition is an evaluation of soil quality based on an interpretation of factors which effect three primary soil functions. The three primary soil functions that are evaluated are soil hydrologic function, soil stability and nutrient cycling. It is important to realize that these functions are interrelated. In addition to an evaluation of soil quality, soil condition is also considered a general evaluation of watershed condition. It is not, however, an evaluation of soil creep, landslides or stream channnel health, nor does it measure sediment yield to a stream channel or determine erosion from a single storm event.
Each dominant map unit component is assigned a soil condition category which is an indication of the status of soil function. Soil condition categories reflect soil disturbances resulting from both planned and unplanned events. Current management activities provide opportunities to maintain or improve soil functions that are critical in sustaining soil productivity. Soil condition categories are satisfactory, impaired or unsatisfactory.

> **Satisfactory -** Indicators signify that soil function is being sustained and the soil is functioning properly and normally. The ability of the soil to maintain resource values and sustain outputs is high.
> **Impaired -** Indicators signify a reduction of soil function. The ability of the soil to function properly and normally has been reduced and/or there exists an increased vulnerability to degradation. An impaired category should indicate to land managers that there is a need to further investigate the ecosystem to determine the cause and degree of decline in soil functions. Changes in land management practices or other preventative actions may be appropriate.
> **Unsatisfactory -** Indicators signify that loss of soil function has occurred. Degradation of vital soil functions result in the inability of the soil to maintain resource values, sustain outputs or recover from impacts. Soils rated in the unsatisfactory category are candidates for improved management practices or restoration designed to recover soil functions."

Thus soil condition for the Prescott National Forest was not based simply on an analysis of soil erosion compared to a tolerable level. In fact, it was possible for a soil classified as satisfactory to have a higher existing (calculated, or estimated) rate of soil loss than one rated as impaired or unsatisfactory.

During the course of the field work for the TES a large amount of data is collected and georeferenced, using aerial photographs of approximately 1:24,000 scale and, more recently, GPS technology. For example, within the approximately 1.4 million acres of the Prescott National Forest soil scientists collected ecological data at 5,149 plots. This included transect data from 2,394 plots and ecological site description data from 453 plots. As a result, a total of 144 ecological map units were identified. Many of these had components which were not practical to delineate separately but which were described and the proportion of area within the map unit estimated to the nearest five percent. Although the soil cover parameters and condition ratings are done at an extensive scale, they are quite appropriate for broad scale evaluations such as this reconnaissance analysis.

Information from the Kaibab National Forest TES was completed early enough to be used in their Forest Plan in the mid-1980's. It was aggregated and rated by vegetative type within 5th code subwatersheds. Three of these were located in the Upper and Middle

Verde watershed – Partridge Creek, Sycamore Canyon, and the area draining to the Verde between these two drainages. A total of 356 thousand acres in the Verde was classified, of which 184 thousand, or 52 percent, was pinyon-juniper woodland, including areas in early successional stages due to having been cleared. Of the pinyon-juniper woodland a little over half (101 thousand acres) was rated as being in unsatisfactory condition due to soil erosion rates exceeding the tolerance level. This was located primarily in the Partridge Creek subwatershed. All other vegetative types were rated as satisfactory or optimum.

Because they have both been completed relatively recently and are on a GIS database it was determined to make a more detailed examination of the TES information for the Coconino and Prescott National Forests. Personnel from both Forests were quite helpful. Both had ongoing needs for analysis and provided information they had drawn from GIS databases. In addition, the Prescott NF did a specific database retrieval for the portions of the Verde Watershed not already covered by ongoing studies. Both Forests provided acres by TES unit by 5th Code Watershed; however, these 5th Code boundaries were then in a draft stage. For purposes of this analysis that breakdown was used as background information to help in identifying areas for selecting sample subwatersheds, but is not specifically included as a part of the report.

Within the Verde Watershed the Prescott National Forest includes about 585 thousand acres or a little over 900 square miles. The Coconino National Forest TES mapped area includes about 912 thousand acres or about 1425 square miles. (This includes some intermingled Arizona State Trust and small private land parcels). The two, together, constitute nearly 2400 square miles, or a little more than half of the watershed. There are significant differences between the two due to geology, terrain and vegetation. For example 60 percent of the portion on the Coconino NF is in TES units of less than 15 percent slope, while only 40 percent of the Prescott is on these gentle slopes. By contrast, about 44 percent of the Prescott NF is on slopes between 15 and 40 percent while only about 23 percent of the Coconino is so located. Due primarily to greater geologic complexity, the Prescott has more ecological map units – 102. Although substantially larger in acreage, the Coconino has 83 map units.

For analysis purposes the TES units were divided by climatic/vegetation gradients into two general classes. The lower elevation gradient class included desert shrub, pinyon-juniper and chaparral. The upper elevation class was made up of ponderosa pine, mixed conifer and associated types such as aspen and mountain grassland. Because the Verde Watershed extends to the top of the San Francisco Peaks, a very small portion of the Coconino is made up of spruce-fir, bristlecone pine, and tundra ecological map units.

Table 6 displays a summary of the soil condition as given in the TES reports and (slightly) modified by soil scientists following further review. The table displays acres by condition class within the two elevational classes of vegetation and by slope class.

TABLE 6. SOIL CONDITION SUMMARY FROM TES REPORTS, COCONINO AND PRESCOTT NATIONAL FORESTS											
UPPER AND MIDDLE VERDE WATERSHEDS											
COCONINO NATIONAL FOREST SOIL CONDITION RATINGS FROM TES SURVEY REPORT											
	Pinyon-juniper and desert shrub						Ponderosa pine, mixed conifer & associated				
Slope in	Acres by Condition Class						Acres by Condition Class				
Percent	Satisfact	Impaired	Unsatisfact	Sat/IU	Total		Satisfac	Impaired	Unsatisfact	Sat/IU	Total
0-15	201,648	5,752	21,628	0	229,028		308,964	2,283	11,467	0	322,714
15-40	14,846	0	36,107	26,669	77,622		77,677	0	9,596	0	87,273
40+	5,596	0	0	144,365	149,961		27,237	0	0	418	27,655
Total	222,090	5,752	57,735	171,034	456,611		413,878	2,283	21,063	418	437,642
PRESCOTT NATIONAL FOREST SOIL CONDITION RATINGS FROM TES SURVEY REPORT											
	Pinyon-juniper, chaparral & desert shrub						Ponderosa pine, mixed conifer & associated				
Slope in	Acres by Condition Class						Acres by Condition Class				
Percent	Satisfact	Impaired	Unsatisfact		Total		Satisfact	Impaired	Unsatisfact		Total
0-15	5,849	92,964	123,300		221,113		7,119	4,806	0		11,925
15-40	109,783	108,649	11,140		229,572		25,586	3432	0		29,018
40+	77,873	4,597	0		82,470		12,425	0	0		12,425
Total	193,505	206,210	134,440		534,155		45,130	8,238	0		53,368

Condition Classes: Satisfactory, Impaired, Unsatisfactory, and Satisfactory/Inherently Unstable

(Prescott National Forest did not have a classification for Satisfactory/Inherently Unstable)

On both Forests the overwhelming majority of the upper elevation vegetation class is classified as satisfactory (95 and 85 percent). None of this is classified as unsatisfactory on the Prescott while 5 percent is on the Coconino. Mountain meadows make up about half of the unsatisfactory portion, with bare soil constituting 70-85 percent of the unit. More than a century of heavy grazing by ungulates – cattle and sheep for the most of that period and elk in recent years, coupled with increasing recreational use and off-road vehicle driving, have contributed to low ground cover density and changed soil structure via compaction. The other portion of unsatisfactory is steeper slopes in the fringe of ponderosa pine with alligator juniper and pinyon pine. Lower productivity results in less litter cover and the steep slopes make the area more vulnerable to erosion.

A review of the lower elevation vegetation -- pinyon-juniper and desert shrub on the Coconino; pinyon-juniper, chaparral, and desert shrub on the Prescott – suggests a contrasting situation, and one that is strongly affected by slope class on the Prescott. In the gentle areas of less than 15 percent slope the Coconino has mostly satisfactory condition ratings (88%) while the Prescott has only 3 percent satisfactory. In the midrange slope class of 15-40 percent the Coconino has most of the area classified as unsatisfactory while the Prescott is about evenly divided between satisfactory and impaired. In the very steep category – over 40 percent – the Coconino has most of the area classified as satisfactory/inherently unstable, while the Prescott has most as satisfactory.

Further analysis of the two Forests reveals that in the low slope area the biggest difference appears to be in criteria for classification. A review of all the Prescott TES units classified as unsatisfactory was made and compared to the criteria used on the Coconino TES. Had the criteria used in the Coconino TES been applied to the Prescott 86 percent would have been satisfactory, another 9 percent unsuited, or satisfactory/ inherently unstable, and only 5 percent as unsatisfactory.

One conclusion to be drawn from this analysis is the inherent danger in using only one primary parameter on which to rate soil condition, i.e., soil stability. Use of the Universal Soil Loss Equation on wildland soils is valuable only as a relative index. Forest Service soil scientists familiar with its use have concerns about the very strong influence of slope in the algorithm. There is a concern that it may overpredict on-site soil loss on steeper slopes and underpredict on very gentle slopes. The average of calculated soil losses over a general area may be reasonable but the individual mapping units may be less accurate (Robertson, 2001).

The Prescott National Forest used three soil functions – hydrologic function, soil stability, and nutrient cycling. These are evaluated using indicators and a tabular guide is provided for use in classification. For example the function of soil stability is evaluated using indicators of rill and gully erosion, pedestalling, erosion pavement, soil deposition, surface ("A") horizon, and vegetative community composition. Documentation of the reason for condition classification of individual TES map units is not well displayed in the report. Field records and notes were examined on a sample basis for TES units within the pinyon-juniper. For units classified as "unsatisfactory" the documentation included presence of active erosion as evidenced by plant pedestalling and litter debris dams, compaction and platy structure near the surface, lack of litter cover for nutrient cycling, loss of portions of the A horizon, et al.

An apparent contradiction in terms was noted, i.e., classifying a unit as unsatisfactory because it naturally produces sediment, even though that is a result of geological conditions rather than management. For example Map Unit 455 is listed as unsatisfactory even though "the ability to improve vegetative ground cover on this map unit is limited due to inherent instability and steep slopes. The condition of this map unit is not expected to change much over time." Similar soils on the Coconino NF were classified as satisfactory/inherently unstable. The definition of unsatisfactory includes the statement that these soils "are candidates for improved management practices or restoration designed to recover soil functions."

Finally, there is an inherent risk in using value laden terms such as "satisfactory" and "unsatisfactory" in natural resource management of public lands. Although the intent is to aid managers assess conditions and set priorities for expenditure of efforts and finances, the terminology conveys an image of management or lack thereof and may be used by outside parties, via the administrative and judicial processes, for purposes beyond its resolution capability. Confining rating or classification systems to descriptive, rather than judgmental, adjectives and phrases would help reduce the chance for misunderstanding and misuse.

C. Hydrologic Function Analysis

Despite the technique's wide use and authoritative origins, Runoff Curve Numbers (CN)s, themselves, are largely a table or graph look-up matter. The origin of the table values are rarely documented, and calibration of the method for CN on field data is rare (Hawkins and Ward, 1998). However, there has been some actual calculation of CN's using data from the Beaver Creek Experimental Watersheds within the Verde watershed (Anderson, 1980; Hawkins, 1998).

Analysis using the CN methodology was done within the pinyon-juniper and desert shrub vegetative types. Curve numbers were determined for current and "natural" conditions by TES unit based on ratings in the TES report. This required combining the soil hydrologic group – A, B, C, or D – with the ground cover to determine the CN. Vegetative basal area, litter cover and rock fragments were totaled as cover. Although rock cover is sometimes discounted for hydrologic evaluations, a comparison of CN with and without including rock fragments as cover was done for Utah juniper watersheds which had actual CN calculated from storm runoff events. Using the classified soil hydrologic group, D, the CN for current condition was much more closely approximated if rock fragments were included as cover. Excluding them resulted in CN that was too high.

In recognition of the fact that large rocks do tend to act as impermeable material rather than providing a gravel mulch effect, reductions were made for soils with surface textures classified as stony, cobbly, or bouldery. A ten percent reduction was applied for stony, 20 percent for very stony, and 30 percent for extremely stony. Similar reductions were used for the cobbly and bouldery descriptions. TES components classified as rock outcrop also had a 50 percent reduction of area allowed to be credited as cover. The intent of the analysis was for purposes of comparison. Use of a consistent methodology for addressing rock cover was believed to allow comparisons based on changes in vegetative & litter cover and bare soil.

Table 7 displays the cover components, total cover, and CN for TES units on the Coconino National Forest within the lower elevation vegetation category, i.e., pinyon-juniper and desert shrub. These display the current condition and that defined as "natural" (which would occur under undisturbed climax conditions) and described in the TES. It is arranged in descending order of the difference in CN between current and natural. As illustrated in Figure 4, about 80 percent of the area of pinyon-juniper and desert shrub has a difference in CN of 1 or more, 50 percent has a difference of 2 or more, and 25 percent has a difference of CN's of 5 or greater.

Using the results of Table 7 an analysis of effects of current and natural cover was done, looking at calculated storm runoff for one hour storms of 2, 5, 10, 25, 50, and 100 year "frequency". (A 2 year frequency storm has a 50 percent probability of occurrence in any given year, a 100 year frequency storm has a 1 percent probability in any year, etc.) Table 8 is arranged in descending order of actual runoff increase in inches for a 10 year one hour storm of 2.3 inches. Increase ranges from none to a high of about 0.3 inches. As Table 8 shows, the weighted average difference amounts to about 0.04 inches for a 2 year storm of 1.4 inches, increasing to 0.15 inches increase for a 100 year storm of 3.4 inches. Another way of expressing it is that the weighted average runoff for natural conditions is about 16 percent less than current for a 2 year storm, declining to about 11 percent for a 100 year storm.

Figure 5 is similar to Figure 4, in illustrating areal distribution of increased runoff. With the 10 year one hour storm of 2.3 inches, about 80 percent of the area has increased runoff of 0.045 inches, 50 percent exceeds 0.085 inch increase, and 25 percents exceeds 0.14 inch increase. For perspective the weighted average current storm runoff from this storm is calculated as 0.464 inches for current conditions and 0.396 inches for natural.

Runoff curve number analysis was done on two sample subwatersheds in the pinyon-juniper and desert shrub vegetation types, one in the Upper Verde on basalt soils (Witty Tom) and one on sedimentary formations and alluvium in the Middle Verde (Sheepshead). Similar analysis was done with the Sawmill watershed with chaparral and pinyon-juniper vegetation on granitic and metamorphic formations, located in the Upper Verde. All indicated some difference between current and natural conditions; however there was considerable variation. The basalt watershed showed the least difference, even though it had a considerable amount of soils classified as unsatisfactory due to past erosion and current low cover density. Figure 6 illustrates the comparison.

TABLE 7. COCONINO NATIONAL FOREST VERDE WATERSHED PINYON-JUNIPER AND DESERT SHRUB
CURRENT AND NATURAL CONDITIONS, PERCENT OF AREA WITH COVER AND RUNOFF CURVE NUMBER

TES#	Hyd	Soil cond	CURRENT CONDITIONS						NATURAL CONDITIONS									
	Soil		Bare	Rock	Veg	Litter	Total	CN	Bare	Rock	Veg	Litter	Total	CN	CN	Acres		
	Grp		Soil				Cov		Soil				Cov		Diff	TES	Cum	Percent
403.2	B	Satisfactory	80	5	10	5	20	**73.7**	60	5	20	15	40	**63.4**	**9**	8499	8499	1.9
414.2	B	UnSatisfactory	80	10	5	5	20	**73.7**	65	10	15	10	35	**66**	**7.7**	1738	10237	2.2
448.1	B	Sat/InhUnst	25	60	5	10	75	**45.5**	10	60	10	20	90	**37.8**	**7.7**	6359	16596	3.6
447.1	B	Satisfactory	70	15	5	10	30	**68.5**	55	15	10	20	45	**61**	**7.5**	3430	20026	4.4
350.2	B	Sat/Inh/Unstab	35	60	3	2	53	**56.5**	20	60	10	10	68	**49.1**	**7.4**	13410	33436	7.3
492.2	C	Satisfactory	40	50	5	5	50	**73**	20	50	10	20	70	**66.2**	**6.8**	18343	51779	11.3
382	C	Satisfactory	65	20	10	5	33	**79**	55	20	20	10	48	**72.8**	**6.2**	2448	54227	11.8
280	B	Impaired	80	10	5	5	20	**74**	70	10	10	10	30	**68.5**	**5.5**	5752	59979	13.1
471.2	B	Sat/Inh/Unstab	40	55	10	25	55	**55.9**	30	55	10	35	65	**50.6**	**5.3**	9044	69023	15.1
463.1	C	UnSatisfactory	30	55	5	10	56	**71**	15	55	10	20	71	**65.8**	**5.2**	10291	79314	17.3
383.1	C	Satisfactory	45	40	10	5	47	**74.1**	35	40	20	10	62	**69**	**5.1**	2215	81529	17.8
493.2	C	Satisfactory	40	45	5	10	50	**73**	25	45	10	20	65	**67.9**	**5.1**	4256	85785	18.7
404	C	UnSatisfactory	35	55	5	5	54	**71.6**	20	55	15	15	69	**66.5**	**5.1**	7945	93730	20.5
495.1	C	Satisfactory	35	50	5	10	55	**71.3**	20	50	10	20	70	**66.2**	**5.1**	9236	102966	22.5
403.1	B	Satisfactory	75	10	10	5	25	**71.1**	65	10	15	10	35	**66**	**5.1**	12745	115711	25.3
385.1	B	Satisfactory	55	35	5	5	45	**61**	45	35	10	10	55	**55.9**	**5.1**	11716	127427	27.8
417.2	B	Satisfactory	72	18	5	5	28	**69.5**	62	18	10	10	38	**64.5**	**5**	636	128063	28.0
474	B	Satisfactory	40	20	10	35	60	**56.4**	30	20	10	45	70	**51.7**	**4.7**	6335	134398	29.4
420.6	B	UnSatisfactory	17	70	5	8	76	**46**	10	70	10	10	83	**41.3**	**4.7**	1472	135870	29.7
381.2	B	Satisfactory	80	5	10	5	26	**70.6**	65	5	20	10	35	**66**	**4.6**	7237	143107	31.3
383.2	C	Satisfactory	55	35	5	5	38	**77.1**	40	35	20	10	53	**72**	**4**	1190	144297	31.5
462.1	C	Satisfactory	30	55	5	10	59	**70**	20	55	10	15	69	**66.5**	**3.5**	14265	158562	34.6
401.2	B	UnSatisfactory	60	30	5	5	40	**63.4**	45	30	15	10	55	**55.9**	**3.5**	466	159028	34.7
417	C	Satisfactory	72	18	5	5	28	**80.5**	62	18	10	10	38	**77.1**	**3.4**	2546	161574	35.3
466.1	C	Satisfactory	50	40	5	5	42	**75.8**	40	40	15	5	52	**72.4**	**3.4**	11982	173556	37.9
462.2	C	Satisfactory	35	50	5	10	55	**71.3**	25	50	10	15	65	**67.9**	**3.2**	14265	187821	41.0
457.1	B	Satisfactory	55	25	5	15	45	**61**	50	25	5	20	50	**58.3**	**2.7**	7084	194905	42.6
475.5	B	Sat/Inh/Unstab	30	50	5	20	55	**55.9**	25	50	5	25	60	**53.2**	**2.7**	1586	196491	42.9
418.1	B	UnSatisfactory	40	45	5	10	60	**53.2**	35	45	5	15	65	**50.6**	**2.6**	3334	199825	43.6
420.5	C	UnSatisfactory	17	70	5	8	62	**69**	10	70	10	10	69	**66.5**	**2.5**	2207	202032	44.1
381.1	B	Satisfactory	70	5	15	10	30	**68.5**	65	5	20	10	35	**66**	**2.5**	13439	215471	47.1
458.1	B	Sat/InhUnst	15	65	5	15	85	**40.3**	10	65	5	20	90	**37.8**	**2.5**	11245	226716	49.5
493.1	D	Satisfactory	30	65	5	10	50	**87.5**	15	65	10	20	65	**85.4**	**2.1**	4256	230972	50.4
492.1	D	Satisfactory	50	40	5	5	40	**88.8**	35	40	15	10	55	**86.8**	**2**	22419	253391	55.3
495.2	D	Satisfactory	35	50	5	10	52	**87.2**	20	50	10	20	67	**85.2**	**2**	3079	256470	56.0
448.2	D	Sat/Inh/Unstab	25	65	5	5	68	**85**	10	65	10	15	83	**83**	**2**	3424	259894	56.8
350.1	D	Sat/InhUnstab	30	65	3	2	49	**87.5**	15	65	10	10	64	**85.6**	**1.9**	24905	284799	62.2
470.1	C	Satisfactory	10	65	10	30	75	**64.5**	5	65	10	40	80	**62.7**	**1.8**	4477	289276	63.2
416.2	C	Sat/InhUnst	35	50	5	10	55	**71.3**	30	50	10	10	60	**69.6**	**1.7**	1881	291157	63.6
430.1	C	Sat/InhUnst	25	60	5	10	59	**70**	20	60	10	10	64	**68.3**	**1.7**	22410	313567	68.5
418.2	C	UnSatisfactory	35	45	5	15	65	**67.9**	30	45	10	15	70	**66.2**	**1.7**	2222	315789	69.0
414.1	D	UnSatisfactory	75	15	5	5	23	**91**	65	15	10	10	33	**89.7**	**1.4**	3228	319017	69.7
463.2	D	UnSatisfactory	30	55	5	10	56	**86.7**	20	55	10	15	66	**85.3**	**1.4**	5542	324559	70.9
401.1	D	UnSatisfactory	60	30	5	5	30	**90.1**	50	30	10	10	40	**88.8**	**1.3**	866	325425	71.1
466.2	D	Satisfactory	50	40	5	5	42	**88.5**	40	40	15	5	52	**87.2**	**1.3**	11982	337407	73.7
385.2	D	Satisfactory	55	35	5	5	45	**88.1**	45	35	10	10	55	**86.8**	**1.3**	14318	351725	76.8
447.2	D	Satisfactory	45	40	5	10	47	**87.8**	35	40	10	15	57	**86.5**	**1.3**	1143	352868	77.1
430.2	D	Sat/InhUnst	20	70	5	5	46	**87.9**	10	70	10	10	56	**86.7**	**1.2**	18065	370933	81.0
420.1	D	Unsatisfactr	17	70	5	8	62	**85.8**	10	70	10	10	69	**84.9**	**0.9**	11039	381972	83.4
470.2	D	Satisfactory	10	65	10	30	38	**89**	5	65	10	40	43	**88.3**	**0.7**	1119	383091	83.7
402	D	UnSatisfactory	30	55	10	5	59	**86.2**	25	55	10	10	64	**85.5**	**0.7**	7385	390476	85.3
416.1	D	Sat/InhUnst	25	60	5	10	60	**86.1**	20	60	10	10	65	**85.4**	**0.7**	2298	392774	85.8
475.2	D	Sat/Inh/Unstab	30	50	5	20	60	**86.1**	25	50	5	25	65	**85.4**	**0.7**	4758	397532	86.8
475.1	D	Sat/InhUnst	30	50*	5	20	20	**91.4**	25	50	5	25	22	**91.1**	**0.3**	4229	401761	87.8
471.1	D	Sat/InhUnst	15	60*	10	20	34	**89.5**	10	60	10	25	36	**89.3**	**0.2**	27131	428892	93.7
457.2	D	Satisfactory	35	45	5	15	65	**85.4**	35	45	5	15	65	**85.4**	**0**	8660	437552	95.6
458.2	D	Sat/Inh/Unstab	15	65	5	15	85	**82.6**	15	65	5	15	85	**82.6**	**0**	11245	448797	98.0
471.3	A	Sat/Inh/Unstab	10	65	10	20	72	**32**	10	65	10	30	72	**32**	**0**	9044	457841	100.0

Components of cover include vegetation basal area, litter, and a portion of surface rock. CN or Runoff Curve Number is based on total effective cover and hydrologic soil group.

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Fig. 4. Percent of Area with Runoff Curve Number Difference between Current and Natural, Coconino National Forest Pinyon-Juniper and Desert Shrub

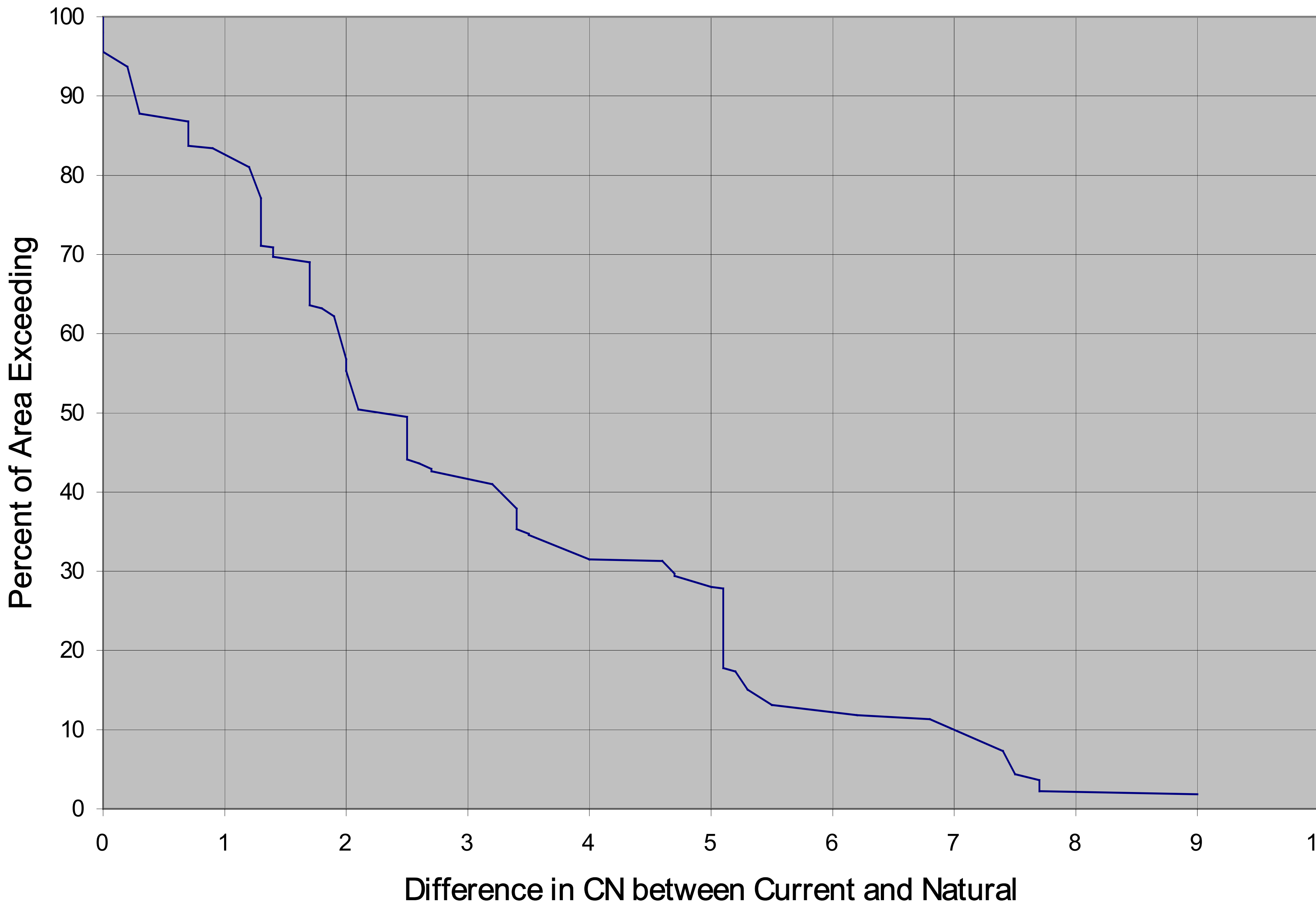


TABLE 8. COCONINO NF VERDE WATERSHED PINYON-JUNIPER & DESERT SHRUB STORM RUNOFF FROM 1 HOUR STORMS OF 2 TO 100 YEAR FREQUENCY FOR CURRENT AND NATURAL CONDITIONS

TES#	Acres	Hyd	CURRENT		NATURAL			2 yr. Ppt. = 1.40 inches					5 yr. Ppt.= 1.9 inches					10 yr. Ppt. = 2.30 inches					25 yr. Ppt. = 2.80 inches					50 yr. Ppt. = 3.05 inches					100 yr. Ppt. = 3.40 inches				
		Gp	Cov	CN	Cov	CN	CN	CURR	NAT	DIFFERENCE			CURR	NAT	DIFFERENCE			CURR	NAT	DIFFERENCE			CURR	NAT	DIFFERENCE			CURR	NAT	DIFFERENCE			CURR	NAT	DIFFERENCE		
			%		%		Diff	inches	inches	inches	ac-ft	%	inches	inches	inches	Ac-ft	%	in	in	in	ac-ft	%	in	in	in	ac-ft	%	in	in	in	ac-ft	%	in.	in.	inches	Ac-ft	%
403.2	8499	B	20	73.7	40	63.4	10.3	0.111	0.01	0.101	71.5	91	0.296	0.085	0.211	149.4	71	0.488	0.19	0.298	211	61	0.77	0.365	0.405	287	53	0.92	0.469	0.455	322	49	1.15	0.629	0.53	372	45
382	2448	C	33	79	48	72.8	6.2	0.214	0.097	0.117	23.9	55	0.465	0.272	0.193	39.4	42	0.706	0.456	0.25	51	35	1.044	0.728	0.316	64	30	1.23	0.878	0.347	71	28	1.49	1.101	0.39	79	26
414.2	1738	B	20	73.7	35	66	7.7	0.111	0.025	0.086	12.5	77	0.296	0.126	0.17	24.6	57	0.488	0.251	0.237	34	49	0.77	0.452	0.318	46	41	0.92	0.569	0.355	51	38	1.15	0.747	0.41	59	35
492.2	18343	C	50	73	70	66.2	6.8	0.1	0.026	0.074	113.1	74	0.277	0.129	0.148	226.2	53	0.463	0.256	0.207	316	45	0.737	0.46	0.277	423	38	0.89	0.577	0.311	475	35	1.11	0.756	0.36	546	32
383.2	1190	C	38	77.1	53	72	5.1	0.172	0.086	0.086	8.5	50	0.39	0.251	0.139	13.8	36	0.622	0.428	0.194	19	31	0.94	0.692	0.248	25	26	1.11	0.838	0.274	27	25	1.36	1.056	0.31	30	23
280	5752	B	20	74	30	68.5	5.5	0.115	0.045	0.07	33.6	61	0.304	0.172	0.132	63.3	43	0.499	0.319	0.18	86	36	0.784	0.546	0.238	114	30	0.94	0.674	0.266	128	28	1.17	0.869	0.3	145	26
447.1	3430	B	30	68.5	45	61	7.5	0.045	0.002	0.043	12.3	96	0.172	0.055	0.117	33.4	68	0.319	0.141	0.178	51	56	0.546	0.292	0.254	73	47	0.67	0.384	0.29	83	43	0.87	0.528	0.34	97	39
383.1	2215	C	47	74.1	62	69	5.1	0.117	0.05	0.067	12.4	57	0.307	0.183	0.124	22.9	40	0.503	0.333	0.17	31	34	0.789	0.565	0.224	41	28	0.95	0.7	0.245	45	26	1.18	0.895	0.28	52	24
493.2	4255	C	50	73	65	67.9	5.1	0.1	0.04	0.06	21.3	60	0.277	0.16	0.117	41.5	42	0.463	0.302	0.161	57	35	0.737	0.522	0.215	76	29	0.89	0.648	0.24	85	27	1.11	0.839	0.27	97	25
417	2546	C	28	80.5	38	77.1	3.4	0.251	0.172	0.079	16.8	31	0.522	0.39	0.132	28.0	25	0.778	0.622	0.156	33	20	1.132	0.94	0.192	41	17	1.32	1.112	0.208	44	16	1.59	1.363	0.23	49	14
404	7945	C	54	71.6	69	66.5	5.1	0.08	0.028	0.052	34.4	65	0.241	0.134	0.107	70.8	44	0.415	0.264	0.151	100	36	0.674	0.47	0.204	135	30	0.82	0.589	0.229	152	28	1.03	0.77	0.26	175	26
463.1	10291	C	56	71	71	65.8	5.2	0.073	0.023	0.05	42.9	68	0.227	0.122	0.105	90.0	46	0.395	0.246	0.149	128	38	0.648	0.445	0.203	174	31	0.79	0.561	0.228	196	29	1	0.737	0.26	226	26
495.1	9236	C	55	71.3	70	66.2	5.1	0.077	0.026	0.051	39.3	66	0.234	0.129	0.105	80.8	45	0.405	0.256	0.149	115	37	0.661	0.46	0.201	155	30	0.8	0.577	0.227	175	28	1.02	0.756	0.26	201	26
403.1	12745	B	25	71.1	35	66	5.1	0.074	0.025	0.049	52.0	66	0.229	0.126	0.103	109.4	45	0.398	0.251	0.147	156	37	0.652	0.452	0.2	212	31	0.79	0.569	0.225	239	28	1.01	0.747	0.26	275	26
350.1	24905	D	49	87.5	64-68	85.3	2.2	0.488	0.401	0.087	180.6	18	0.856	0.738	0.118	244.9	14	1.178	1.039	0.139	288	12	1.603	1.443	0.16	332	10	1.82	1.653	0.169	351	9	2.14	1.953	0.18	378	9
492.1	22419	D	40	88.8	55	86.8	2	0.547	0.459	0.088	164.4	16	0.933	0.817	0.116	216.7	12	1.267	1.133	0.134	250	11	1.704	1.551	0.153	286	9	1.93	1.767	0.161	301	8	2.25	2.076	0.17	319	8
493.1	4256	D	50	87.5	65	85.4	2.1	0.488	0.404	0.084	29.8	17	0.856	0.743	0.113	40.1	13	1.178	1.045	0.133	47	11	1.603	1.45	0.153	54	10	1.82	1.66	0.162	57	9	2.14	1.962	0.17	61	8
417.2	636	B	28	69.5	38	64.5	5	0.056	0.015	0.041	2.2	73	0.193	0.101	0.092	4.9	48	0.348	0.215	0.133	7	38	0.586	0.401	0.185	10	32	0.72	0.51	0.209	11	29	0.92	0.677	0.24	13	26
381.2	7237	B	26	70.6	35	66	4.6	0.068	0.025	0.043	25.9	63	0.218	0.126	0.092	55.5	42	0.382	0.251	0.131	79	34	0.631	0.452	0.179	108	28	0.77	0.569	0.201	121	26	0.98	0.747	0.23	140	24
401.2	466	B	40	63.4	55	55.9	7.5	0.01	0	0.01	0.4	100	0.085	0.013	0.072	2.8	85	0.19	0.061	0.129	5	68	0.365	0.164	0.201	8	55	0.47	0.232	0.237	9	51	0.63	0.342	0.29	11	46
66.1	11982	C	42	75.8	52	72.4	3.4	0.147	0.091	0.056	55.9	38	0.357	0.261	0.096	95.9	27	0.569	0.442	0.127	127	22	0.873	0.71	0.163	163	19	1.04	0.858	0.18	180	17	1.28	1.079	0.2	202	16
495.2	3079	D	52	87.2	67	85.2	2	0.476	0.397	0.079	20.3	17	0.839	0.733	0.106	27.2	13	1.159	1.033	0.126	32	11	1.581	1.436	0.145	37	9	1.8	1.645	0.155	40	9	2.11	1.945	0.17	42	8
448.2	3424	D	68	85	83	83	2	0.39	0.323	0.067	19.1	17	0.723	0.628	0.095	27.1	13	1.021	0.907	0.114	33	11	1.422	1.287	0.135	39	9	1.63	1.487	0.143	41	9	1.93	1.775	0.16	44	8
462.2	14265	C	55	71.3	65	67.9	3.4	0.077	0.04	0.037	44.0	48	0.234	0.16	0.074	88.0	32	0.405	0.302	0.103	122	25	0.661	0.522	0.139	165	21	0.8	0.648	0.156	185	19	1.02	0.839	0.18	212	18
462.1	14265	C	59	70	69	66.5	3.5	0.061	0.028	0.033	39.2	54	0.204	0.134	0.07	83.2	34	0.363	0.264	0.099	118	27	0.606	0.47	0.136	162	22	0.74	0.589	0.153	182	21	0.95	0.77	0.18	210	19
414.1	3228	D	23	91	33	89.7	1.3	0.66	0.591	0.069	18.6	10	1.077	0.99	0.087	23.4	8	1.43	1.332	0.098	26	7	1.886	1.777	0.109	29	6	2.12	2.004	0.114	31	5	2.45	2.327	0.12	32	5
401.1	866	D	30	90.1	40	88.8	1.3	0.611	0.547	0.064	4.6	10	1.016	0.933	0.083	6.0	8	1.361	1.267	0.094	7	7	1.81	1.704	0.106	8	6	2.04	1.928	0.111	8	5	2.36	2.247	0.12	8	5
466.2	11982	D	42	88.5	52	87.2	1.3	0.533	0.476	0.057	56.9	11	0.915	0.839	0.076	75.9	8	1.246	1.159	0.087	87	7	1.68	1.581	0.099	99	6	1.9	1.799	0.105	105	6	2.22	2.11	0.11	111	5
463.2	5542	D	56	86.7	66	85.3	1.4	0.455	0.401	0.054	24.9	12	0.812	0.738	0.074	34.2	9	1.126	1.039	0.087	40	8	1.544	1.443	0.101	47	7	1.76	1.653	0.106	49	6	2.07	1.953	0.12	53	6
385.2	14318	D	45	88.1	55	86.8	1.3	0.515	0.459	0.056	66.8	11	0.891	0.817	0.074	88.3	8	1.219	1.133	0.086	103	7	1.649	1.551	0.098	117	6	1.87	1.767	0.104	124	6	2.19	2.076	0.11	131	5
447.2	1143	D	47	87.8	57	86.5	1.3	0.501	0.447	0.054	5.1	11	0.874	0.801	0.073	7.0	8	1.199	1.114	0.085	8	7	1.626	1.529	0.097	9	6	1.85	1.744	0.103	10	6	2.16	2.051	0.11	10	5
385.1	11716	B	45	61	55	55.9	5.1	0.002	0	0.002	2.0	100	0.055	0.013	0.042	41.0	76	0.141	0.061	0.08	78	57	0.292	0.164	0.128	125	44	0.38	0.232	0.152	148	40	0.53	0.342	0.19	182	35
430.2	18065	D	46	87.9	56	86.7	1.2	0.506	0.455	0.051	76.8	10	0.88	0.812	0.068	102.4	8	1.205	1.126	0.079	119	7	1.634	1.544	0.09	135	6	1.86	1.759	0.096	145	5	2.17	2.068	0.1	152	5
420.5	2207	C	62	69	69	66.5	2.5	0.05	0.028	0.022	4.0	44	0.183	0.134	0.049	9.0	27	0.333	0.264	0.069	13	21	0.565	0.47	0.095	17	17	0.7	0.589	0.111	20	16	0.9	0.77	0.13	23	14
381.1	13439	B	30	68.5	35	66	2.5	0.045	0.025	0.02	22.4	44	0.172	0.126	0.046	51.5	27	0.319	0.251	0.068	76	21	0.546	0.452	0.094	105	17	0.67	0.569	0.105	118	16	0.87	0.747	0.12	137	14
350.2	13410	B	53	56.5	68	49.1	7.4	0	0	0	0.0	0	0.016	0	0.016	17.9	100	0.068	0.005	0.063	70	93	0.177	0.048	0.129	144	73	0.25	0.084	0.164	183	66	0.36	0.151	0.21	236	58
420.1	11039	D	62	85.8	69	84.9	0.9	0.42	0.386	0.034	31.3	8	0.764	0.718	0.046	42.3	6	1.07	1.015	0.055	51	5	1.478	1.415	0.063	58	4	1.69	1.623	0.067	62	4	1.99	1.922	0.07	66	4
416.2	1881	C	55	71.3	60	69.6	1.7	0.077	0.057	0.02	3.1	26	0.234	0.195	0.039	6.1	17	0.405	0.351	0.054	8	13	0.661	0.59	0.071	11	11	0.8	0.724	0.08	13	10	1.02	0.926	0.09	14	9
430.1	22410	C	59	70	64	68.3	1.7	0.061	0.044	0.017	31.7	28	0.204	0.168	0.036	67.2	18	0.363	0.313	0.05	93	14	0.606	0.538	0.068	127	11	0.74	0.666	0.076	142	10	0.95	0.859	0.09	164	9
471.2	9044	B	55	55.9	65	50.6	5.3	0	0	0	0.0	0	0.013	0	0.013	9.8	100	0.061	0.012	0.049	37	80	0.164	0.068	0.096	72	59	0.23	0.111	0.121	91	52	0.34	0.187	0.16	117	45
470.2	1119	D	38	89	43	88.3	0.7	0.556	0.524	0.032	3.0	6	0.946	0.903	0.043	4.0	5	1.281	1.232	0.049	5	4	1.72	1.665	0.055	5	3	1.95	1.887	0.058	5	3	2.27	2.204	0.06	6	3
474	6335	B	60	56.4	70	51.7	4.7	0	0	0	0.0	0	0.015	0	0.015	7.9	100	0.067	0.019	0.048	25	72	0.175	0.084	0.091	48	52	0.25	0.133	0.112	59	46	0.36	0.216	0.14	75	40
457.1	7084	B	45	61	50	58.3	2.7	0.002	0	0.002	1.2	100	0.055	0.029	0.026	15.3	47	0.141	0.094	0.047	28	33	0.292	0.22	0.072	43	25	0.38	0.299	0.085	50	22	0.53	0.425	0.1	61	20
418.2	2222	C	65	67.9	70	66.2	1.7	0.04	0.026	0.014	2.6	35	0.16	0.129	0.031	5.7	19	0.302	0.256	0.046	9	15	0.522	0.46	0.062	11	12	0.65	0.577	0.071	13	11	0.84	0.756	0.08	15	10
402	7385	D	59	86.2	64	85.5	0.7	0.435	0.408	0.027	16.6	6	0.785	0.748	0.037	22.8	5	1.095	1.051	0.044	27	4	1.507	1.457	0.05	31	3	1.72	1.668	0.053	33	3	2.03	1.97	0.06	34	3
416.1	2298	D	60	86.1	65	85.4	0.7	0.431	0.404	0.027	5.2	6	0.779	0.743	0.036	6.9	5	1.088	1.045	0.043	8	4	1.5	1.45	0.05	10	3	1.71	1.66	0.053	10	3	2.02	1.962	0.06	11	3
475.2	4758	D	60	86.1	65	85.4	0.7	0.431	0.404	0.027	10.7	6	0.779	0.743	0.036	14.3	5	1.088	1.045	0.043	17	4	1.5	1.45	0.05	20	3	1.71	1.66	0.053	21	3	2.02	1.962	0.06	22	3
470.1	4477	C	75	64.5	80	62.7	1.8	0.015	0.007	0.008	3.0	53	0.101	0.076	0.025	9.3	25	0.215	0.175	0.04	15	19	0.401	0.343	0.058	22	14	0.51	0.443	0.067	25	13	0.68	0.599	0.08	29	12
475.5	1586	B	55	58.9	60	53.2	2.7	0	0	0	0.0	0	0.013	0.002	0.011	1.5	85	0.061	0.031	0.03	4	49	0.164	0.11	0.054	7	33	0.23	0.165	0.067	9	29	0.34	0.258	0.08	11	25
475.1	4229	D	20	91.4	22	91.1	0.3	0.682	0.665	0.017	6.0	2	1.105	1.084	0.021	7.4	2	1.461	1.437	0.024	8	2	1.92	1.894	0.026	9	1	2.15	2.127	0.027	10	1	2.48	2.456	0.03	10	1
418.1	3334	B	60	53.2	65	50.6	2.6	0	0	0	0.0	0	0.002	0	0.002	0.6	100	0.031	0.012	0.019	5	61	0.11	0.068	0.042	12	38	0.17	0.111	0.054	15	33	0.26	0.187	0.07	20	28
471.1	27131	D	34	89.5	36	89.3	0.2	0.581	0.571	0.01	22.6	2	0.977	0.964	0.013	29.4	1	1.317	1.303	0.014	32	1	1.76	1.744	0.016	36	1	1.99	1.97	0.017	38	1	2.31	2.292	0.02	38	1
420.6	1472	B	76	46	83	41.3	4.7	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0	0	0.017	0	0.017	2	100	0.04	0.003	0.037	5	93	0.09	0.021	0.07	8	76
448.1	6359	B	75	45.5	90	37.8	7.7	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0	0	0.013	0	0.013	7	100	0.03	0	0.034	18	100	0.08	0.001	0.08	41	99
457.2	8660	D	65	85.4	65	85.4	0	0.404	0.404	0	0.0	0	0.743	0.743	0	0.0	0	1.045	1.045	0	0	0	1.45	1.45	0	0	0	1.66	1.66	0	0	0	1.96	1.962	0	0	0
458.1	11245	B	85	40.3	90	37.8	2.5	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	1	100	0.01	0.001	0.01	11	92
458.2	11245	D	85	82.6	85	82.6	0	0.31	0.31	0	0.0	0	0.61	0.61	0	0.0	0	0.886	0.886	0	0	0	1.262	1.262	0	0	0	1.46	1.459	0	0	0	1.75	1.745	0	0	0
471.3	9044	A	72	32	72	32	0	0	0	0	0.0	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	457840							0.242	0.203	0.039	1495	16.2	0.464	0.396	0.068	2587	14.6	0.676	0.585	0.092	3498	13.6	0.973	0.852	0.120	4596	12.4	1.132	0.998	0.134	5131	11.9	1.365	1.211	0.154	5865	11.3

Fig. 5. Percent of Area with Increased Runoff between Natural and Current, Coconino National Forest Pinyon-Juniper and Desert Shrub

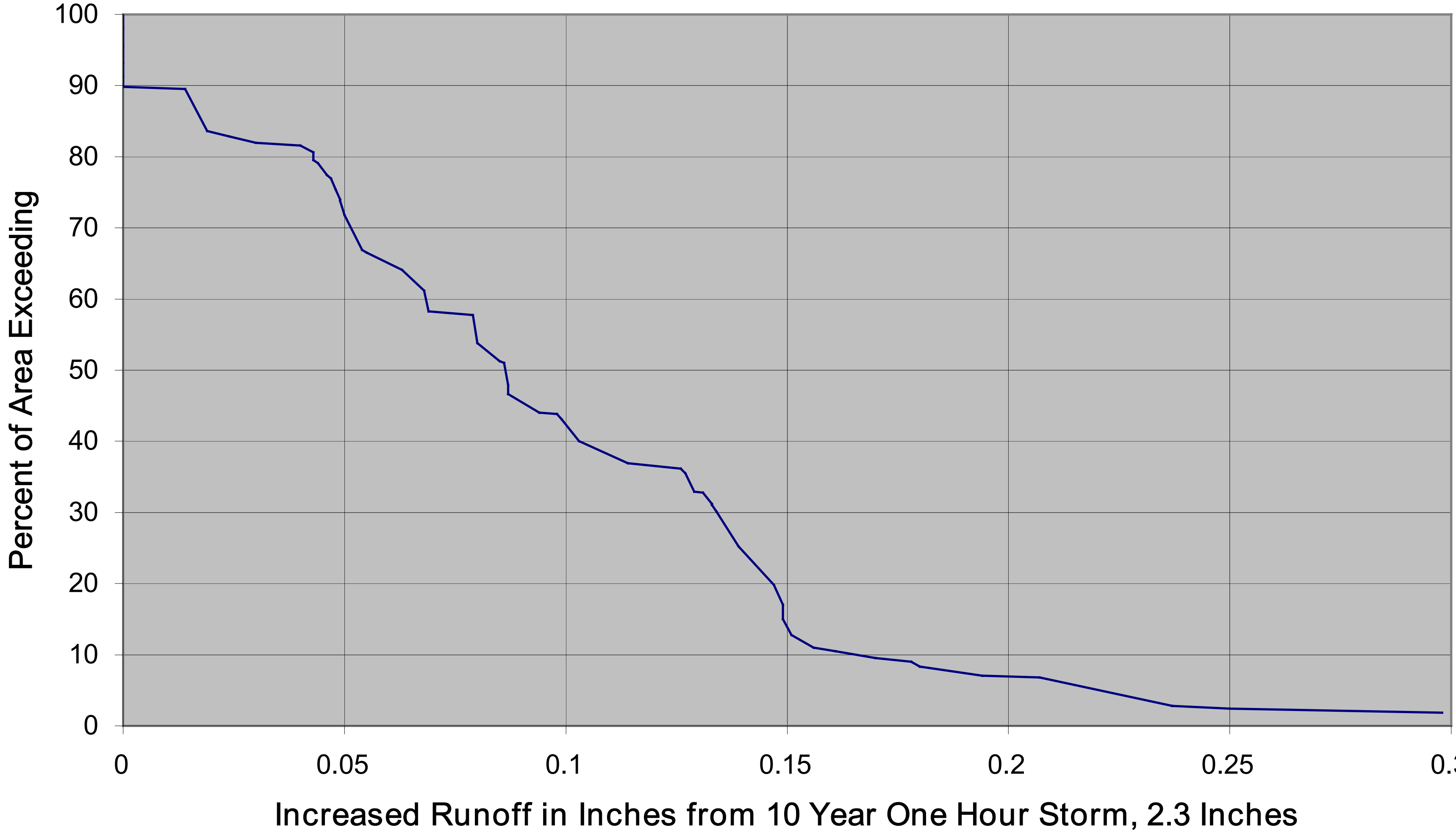
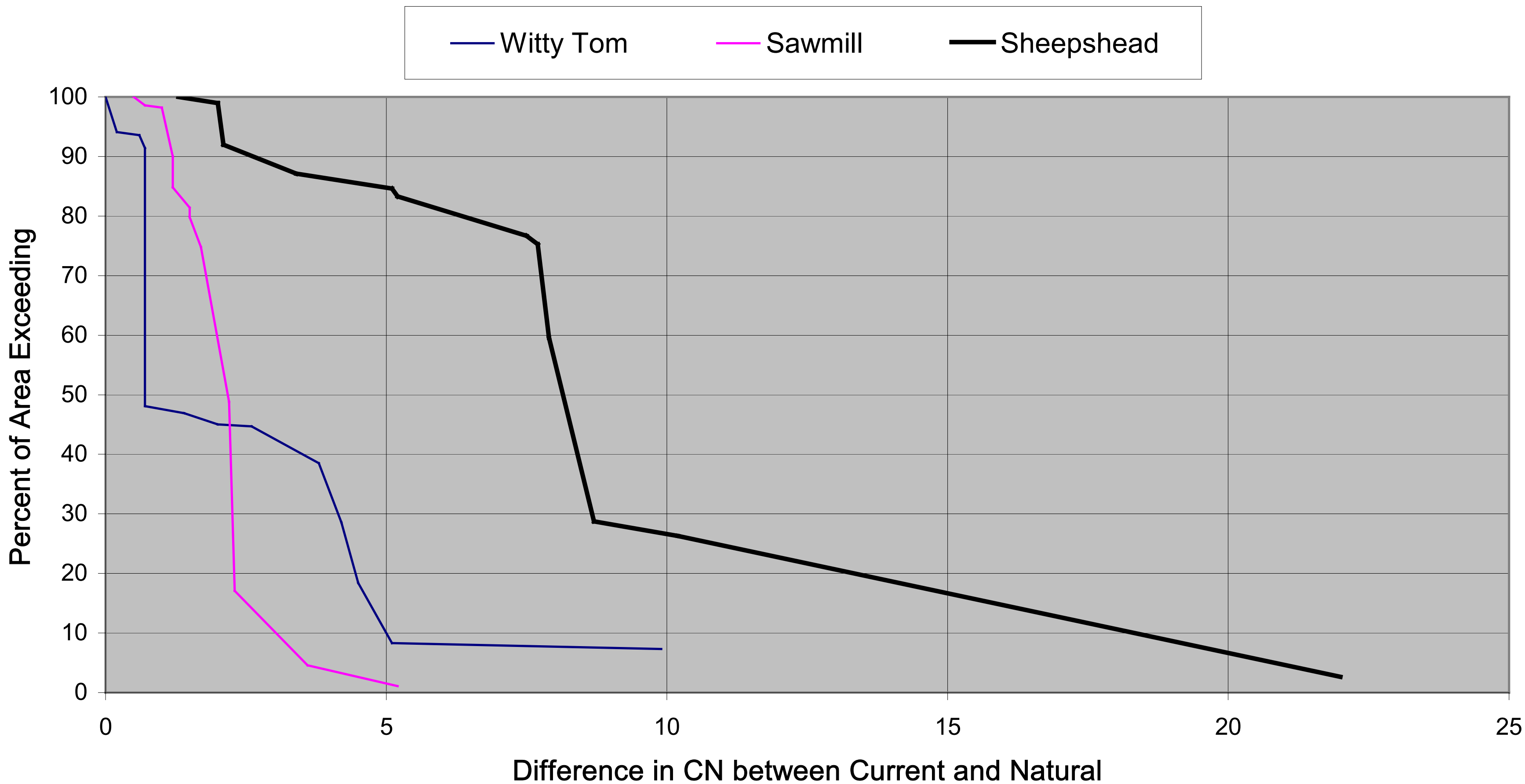


Fig. 6. Percent of Area with Runoff Curve Number Differences between Current and Natural, Sample Subwatersheds



Figures 7 and 8 display the calculated peak flows for current and natural conditions for Witty Tom and Sheepshead sample subwatersheds, respectively, for recurrence intervals between 2 and 100 years. As these show, there is some increase for Witty Tom. Flows calculated for natural conditions are currently occurring more often than under the natural conditions. For example the flow from a 10 year storm under natural conditions is occurring on a 8 year frequency currently, the flow from a 25 year storm under natural conditions is currently occuring on a 18 year frequency, etc. By contrast, the increase in frequency for Sheepshead is several fold. The flow from a 10 year storm under natural conditions is occurring on a 2.2 year frequency currently, the flow from a 25 year storm under natural conditions is currently occurring on a 7 year frequency, etc. Table 9 illustrates this comparison.

Table 9. Effect of Current Condition on Frequency of Storm Peak Flows

Witty Tom				Sheepshead	
Natural Condition Frequency	Current Condition Frequency	Ratio of Current to Natural		Current Condition Frequency	Ratio of Current to Natural
Years	Years			Years	
2					
5	4	1.25		<2	>2.5
10	8	1.25		2.2	4.55
25	18	1.39		7	3.57
50	36	1.39		15	3.33
100	60	1.67		25	4.00

Field review found a strong correlation between these differences and the condition of stream channels. In the Witty Tom watershed there were some areas of unstable channels below areas of disturbance and where influenced by roads. However, the majority of the length of channel inspected is in stable condition. Some of this is due to the materials forming channels in the lower portion of the canyon, with large proportions of cobble, boulders, and bedrock outcrops.

The Sheepshead watershed has highly unstable channels with both historic and current active erosion. A Forest Service channel inventory in 1981 found a density of more than 5 miles per square mile of gullies and eroding channels in one TES unit area and a density of 4 miles per square mile in another in the lower section of the watershed. Field reviews suggested these figures are low, especially in the lower portion. Headcuts of six to 20 feet or more are common, straight-walled channels may be deeper than their top width, block slumping is common and material is being moved down channel by storm flows.

The Sawmill sample watershed is somewhat intermediate between these two. Field review found generally stable channels in the upper portion of the watershed dominated by chaparral; however, there is a considerable amount of natural movement of sediment

Fig. 7. Witty Tom Subwatershed Peak Flows under Current and Natural Conditions

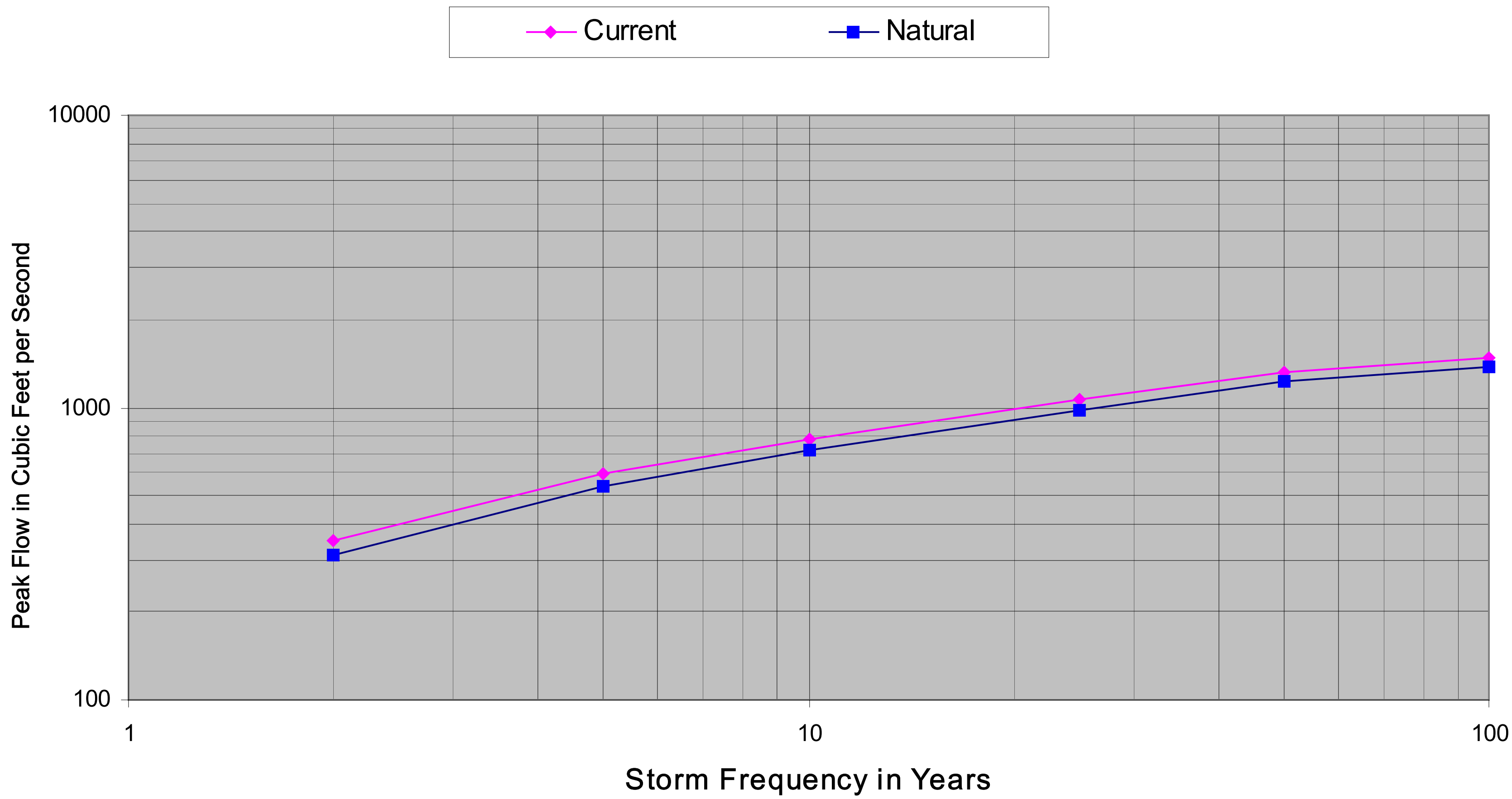
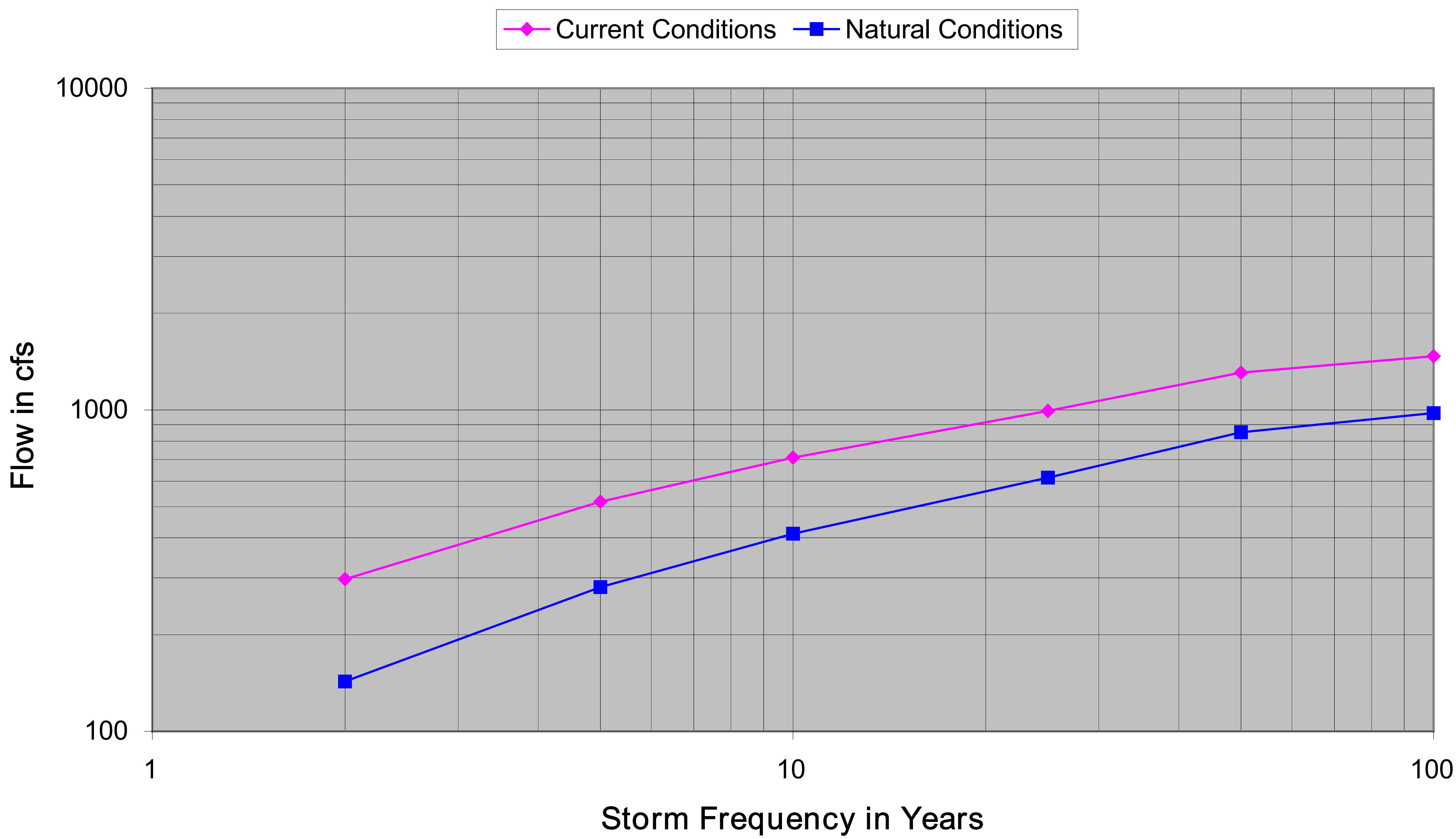


Fig. 8. Sheepshead Subwatershed Peak Flows for Current and Natural Conditions



from the coarse grained granitic and schist derived soils. In the lower part of the watershed where the influence of some pinyon-juniper areas, along with road drainage, becomes evident there are some segments of channels with active erosion.

The analysis revealed differential opportunities for improving surface hydrologic function. Figures 9 and 10 illustrate the opportunities by TES for Witty Tom and Sheepshead watersheds. However, the acres available must also be factored in. In Witty Tom units making up 28 percent of the watershed provide 67 percent of the opportunity for storm runoff reduction. In Sheepshead the opportunity is more evenly distributed. Landownership is not a factor. The opportunities for improvement on Arizona State trust land and National Forest are essentially proportional to their acreages.

Where information was available, time trends were evaluated to determine if the condition is changing. Forest Service Parker three-step transects were established in the 1950's and 1960's and subsequently reread at varying increments of time. A comparison was made of ground cover over these varying time periods. No general conclusions could be drawn regarding changing conditions. There was considerable variation in individual transects over time. The single factor which appeared to most affect the change was weather – seasonal and annual precipitation. Effects of land use could sometimes be inferred and there were reported changes in protocol for evaluating litter and bare soil.

On the Witty Tom Watershed transects were primarily located in areas which had received treatment to remove pinyon and juniper trees. Four transects were initiated in 1955 and 1965, two were reread in 1975 and all in 1997. The last reading in 1997 had essentially the same ground cover density as 1965 on two transects and below on the remaining two. The one transect in a relatively dense pinyon-juniper stand had no net change in vegetation and litter cover. However, the amount of bare soil was reduced at the expense of rock fragments, indicating that fine materials had been removed, leaving rock fragments, and tending toward development of an erosion pavement.

A transect in the headwaters of the Sheepshead watershed was measured at 28 percent ground cover in 1955, rose to 55 percent in 1963, declined to 33 percent in 1972, was measured at 32 percent in 1990 and 57 percent in 2000. A change in grazing management was made in the mid-1970's. Another, established in 1964 but not subsequently reread, was found in field review and a 400 point pace transect taken paralleling the transect a few feet on either side. The result was essentially the same as in 1964, with 75 to 80 percent bare soil and evidence of active erosion occurring.

In addition to the sample watersheds a review was made of analysis in the Partridge Creek Allotment on the Kaibab National Forest, in pinyon-juniper and interspersed grassland. Reported ground cover on five transects changed consistently over time in four measurements between 1963 and 1989 (i.e., they tended to generally increase or decrease in cover at the same time). This was the case both for the four transects described as being in primary use areas and one in a pinyon-juniper area of lighter use.

Fig. 9.   Witty Tom Watershed Storm Runoff from 10 Year 6 Hour Storm

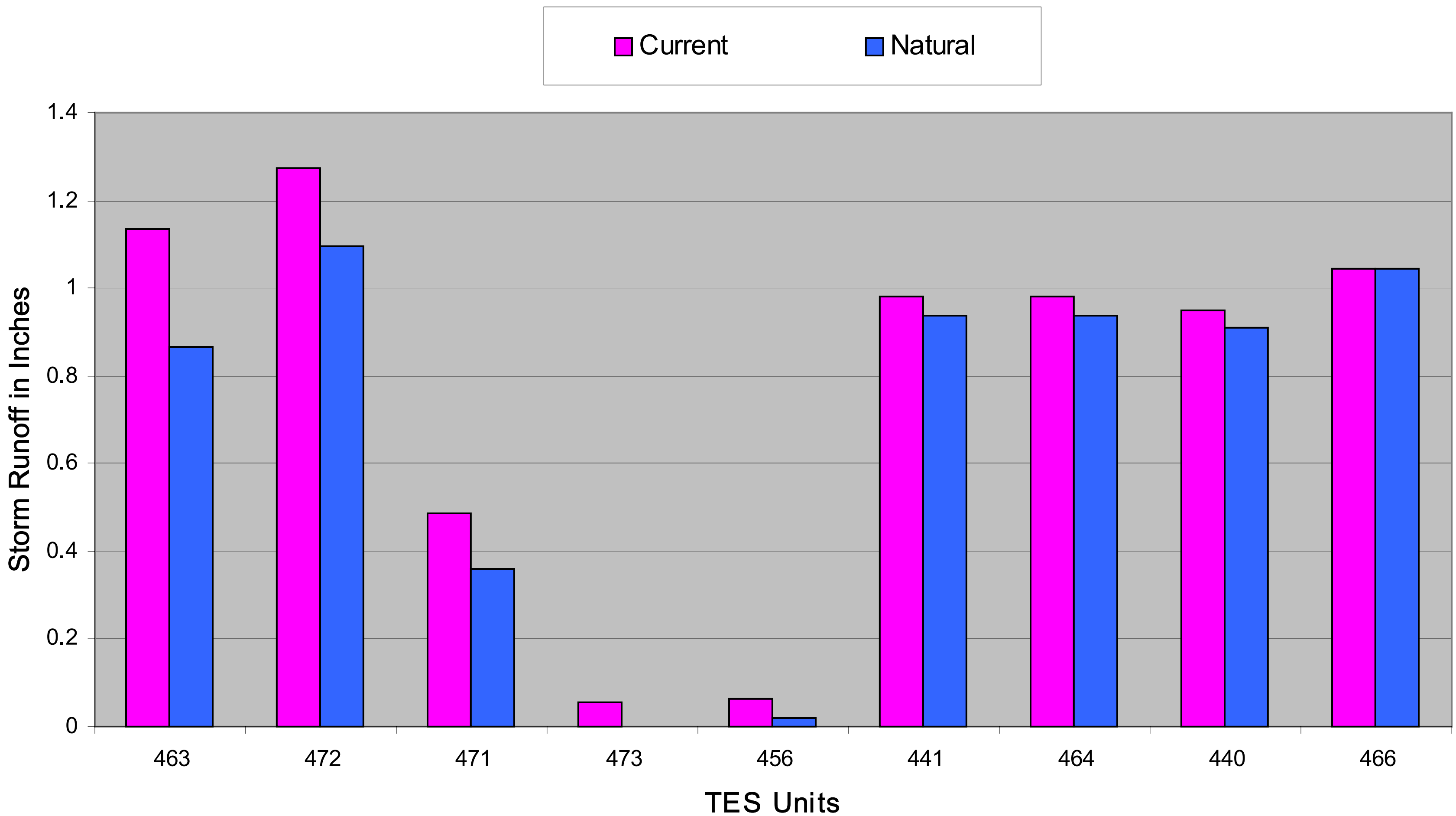
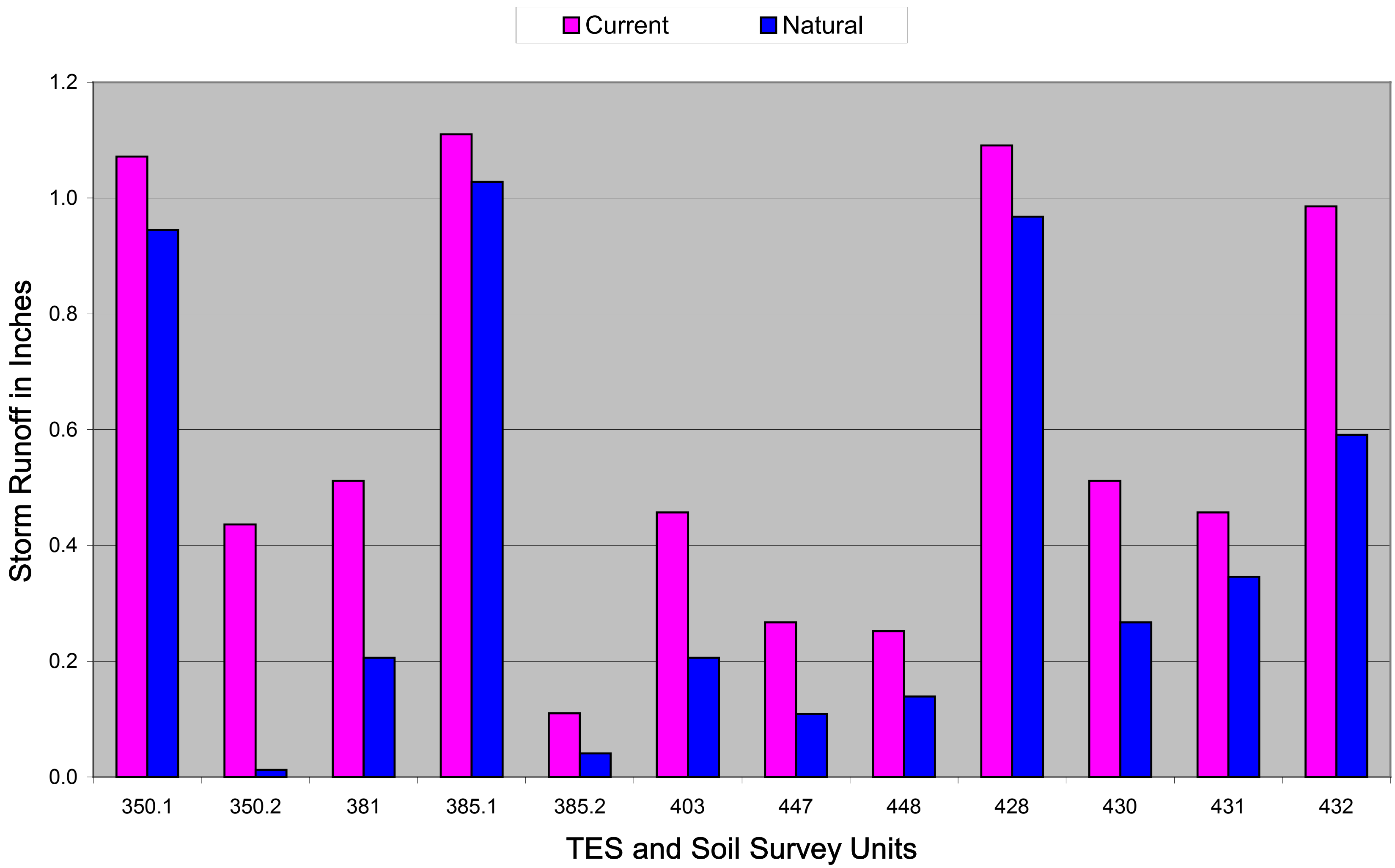


Fig. 10. Sheepshead Watershed Storm Runoff from 10 Year 6 Hour Storm



A more intensive study was conducted on the Yavapai Ranch in the 1990's (Coordinated Resource Planning Team…, 1998). Intensive measurements were taken annually from 1992 through 1998 on paired grazed and ungrazed plots. The results showed wide variation in both grazed and ungrazed plots in protective ground cover and bare soil. For example one ungrazed site had 42 percent bare soil in 1992, improved to only 24 percent in 1994, but was back at 43 percent bare soil in 1998. Its paired grazed plot started at 38 percent, improved to 33 percent and ended at 43 percent. An unusually dry winter of 1995-96 apparently affected all plots.

In the two sample watersheds in ponderosa pine and associated vegetation types, ground cover was found to be effective and well distributed, with the exception of open grassland in the Cougar Park watershed. These open meadows had a long history of livestock concentration and more recently by elk. However, the primary channels did not reflect excessive storm flows.

Urbanization affects storm runoff, normally by the greatly increased flow from rooftops, driveways, sidewalks, streets, and parking lots. However, some practices can reduce storm runoff, depending on soil conditions and the practices. Figures 11 and 12 display the calculated differences between two soil units in the Big Park watersheds, both developed from the red rock formations in that area. Unit 403.2 is a deep fine sandy loam and is in Hydrologic Soil Group B, while unit 458.2 is a quite shallow and extremely gravelly sandy loam, rated group D. As displayed in Figures 11 and 12 the effects of development are much more pronounced on the group B soil. Although there is some difference between current and natural on 403.2 the degree of historic and current human use is unlikely to allow it to achieve that condition in the foreseeable future. Picking a midpoint frequency, the 10 year storm, paved areas yield about five times the amount of runoff as current undeveloped conditions. By contrast, turf areas – golf courses, park areas, etc. – produce only about 15 percent of the current condition. Areas which are mulched, e.g., gravel or decomposed granite spread over an area without an impervious barrier from the soil, produce no runoff. Using the differences, the relative amounts of surface area to maintain a balance of no net change can be calculated. In this example one acre of impervious surface would be counterbalanced by 4.3 acres of turf or 3.7 acres of mulched area[1]. By contrast on the hydrologic D soil, 458.2, it would take 6.6 acres of either turf or mulch to compensate for the increased runoff from one acre of roof and/or pavement.

A comparison of the east and west Big Park watersheds bears this out. In their natural condition (prior to development) the calculated peak flows are quite similar. However, a look at the channels both from aerial photos and actual indicates the east to have more flashy flows, apparently due to the amount of contiguous sandstone outcrops and steep slopes with very shallow soils on sandstone. In addition, a differential development has occurred. On both the primary development has occurred on the Hydrologic Group B

[1] These are calculated differences based on average conditions. They reflect relative differences but should not be used for design purposes. Development design should be based on site specific analysis.

Fig. 11 Big Park Watersheds, Development Effects on TES Unit 403.2 (deep fine sandy loam), Hydrologic Soil Group B

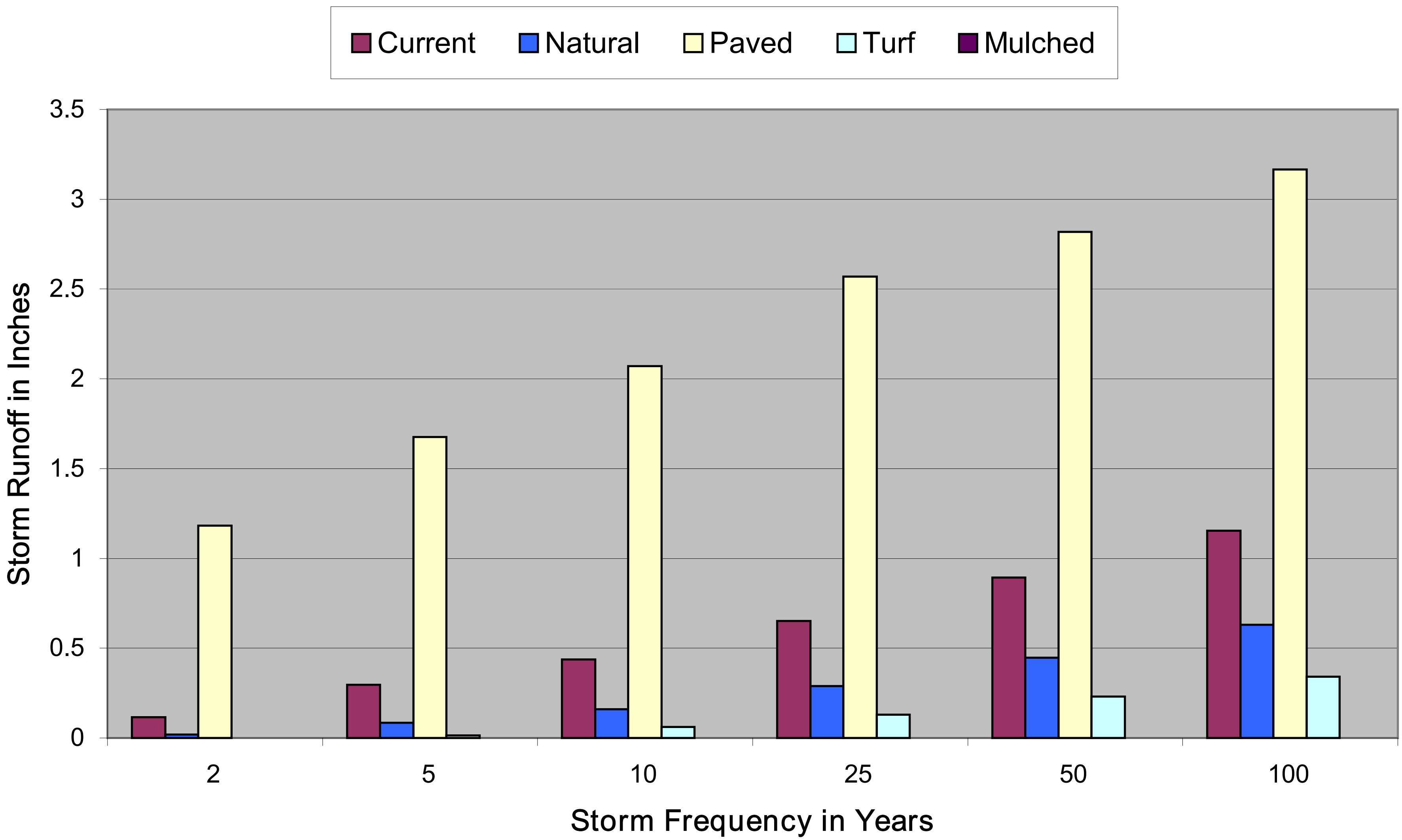
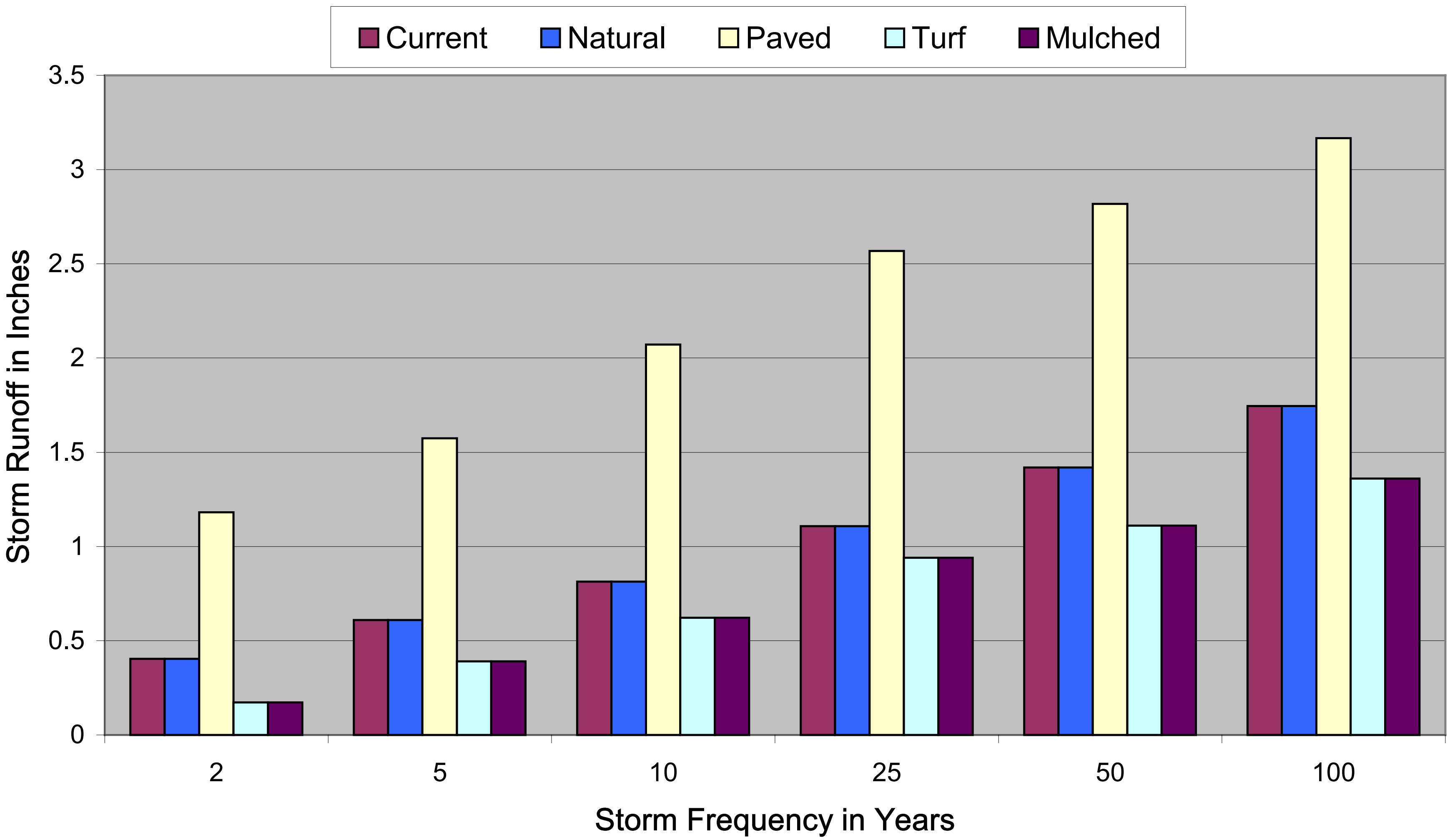


Fig. 12 Big Park Watersheds, Development Effects on TES Unit 458.2 (shallow extremely gravelly sandy loam), Hydrologic Soil Group D



soil, 403.2. On the east side there is an outlet mall with paved parking area, more dense housing areas, and commercial areas with motels, and retail areas. On the west there are one golf course and the majority of a second, school play and athletic fields, plus a generally lower density of housing – a large number having a gravel mulch for primary landscaping. An examination of the two channels reflects a major difference. The east channel is actively eroding downstream from the developed area and has flooded its banks recently. The west channel appears quite benign by comparison, with little evidence of erosion or major flood flows.

D. Combined Condition Analysis – an analysis of watershed condition for a portion of the Verde Watershed within the Prescott National Forest was conducted by staff from that National Forest (Prescott National Forest, 2001). It was prepared to address critical habitat for the spikedace and loach minnow within the Verde River. The analysis combined soil condition, aquatic condition, and riparian condition and then developed a rating system for "watershed condition" and classified watersheds as exhibiting "high", "medium", or "low" "geomorphic, hydrologic, and biotic integrity relative to their natural potential condition". A detailed analysis, including field sampling and investigation was used to arrive at components of the classification system with extensive use of the TES inventory as a starting point. Field evaluations included channel stability, presence of various types of erosion and sedimentation, effects of roads, and vegetation stability. Five fifth code watersheds, ranging in size from about 20 thousand to 175 thousand acres were evaluated. One was classified as exhibiting high integrity compared to its natural potential (Sycamore Canyon), three as moderate, and one as low (Hell Canyon). This analysis and its documentation was the most comprehensive found in the watershed.

In the Prescott National Forest analysis Verde River water quality and riparian condition were evaluated as being in better functioning condition than significant portions of the upland watershed (moderate to low integrity relative to potential). This is not fully consistent with many widespread beliefs that the stream reflects the watershed. It is likely a reflection of the much greater resilience of the riparian and aquatic ecosystem to recover from impacts than the uplands -- especially the pinyon-juniper and desert shrub vegetative communities. The upper Verde River was heavily scoured by floods in 1993 and again in 1995 leaving nothing but gravel and sand bars in many reaches. Subsequently livestock grazing was removed from the National Forest portion of the river. This, along with the natural recovery abilities, enabled the riparian vegetation to return very rapidly. Seven years later, in the spring of 2002, there are locations with very dense riparian vegetation 20 feet or more in height, portions of the channel have become narrower and deeper, and some marshy, or boggy, areas supporting riparian vegetation have developed within the floodplain.

There are limitations to using ground cover density as a surrogate for watershed condition. It is the most commonly available parameter over large areas, and provides some historical comparison. However, by itself it may not adequately reflect comparative conditions. Ambos, et al (2000) found major differences in bulk density between grazed and protected portions of the same site and soil in pinyon-juniper woodland on the Tonto National Forest (1.22 vs. 0.98 or an increase of 24 percent). However, the differences in cover were not enough to generate the differences in infiltration capacity (indirectly through Curve Number analysis) expected based on the bulk density differences (Ambos, 2002). Additional parameters need to be evaluated, at least on a sample basis, to adequately serve as a measure of upland watershed condition. Soil physical features such as bulk density, structure of surface and near surface horizons, size and distribution of pores, and presence and distribution of organic matter all have effects on hydrologic function. Resistance to penetration is another easily obtained index which might be considered in developing a field protocol.

Although the analysis with the Runoff Curve Number procedure indicated greater surface runoff from rainstorms, this is not all available for downstream users. Summer monsoon storms are often quite localized and a given frequency of storm may not occur over a large area at the same time. Some of the storm runoff water is used in wetting channels and some is impounded in stock tanks. However, the most important aspect is that the amount of runoff from intense monsoon storms provides only a small percentage of the streamflow delivered to downstream storage reservoirs. Increased storm runoff results in greater on-site soil erosion and reduced productivity. In addition it may reduce the opportunity for any contributions to ground-water recharge which might occur from these areas.

E. Water Yield

Current condition as related to water yield was evaluated using both a macro and micro approach. Sample watersheds within the ponderosa pine were evaluated for their condition relative to water yield and opportunities for increase. In addition, the overall picture of water yield for t he watershed was evaluated, looking at trends over time.

Ponderosa pine - One of the sample watersheds, Watershed 8, was located within the Beaver Creek Watersheds and was treated in 1974 to evaluate increases in yield. This evaluation did not find significant potential to further increase water yield.

The Beaver Creek Research watersheds included 20 gaged watersheds, of which 12 are in ponderosa pine. All of the Beaver Creek watersheds have ephemeral flow, i.e., from storm runoff or snowmelt. There is no perennial, or base flow. Six of the ponderosa pine watersheds were treated to evaluate a range of treatment alternatives, ranging from clearcutting the entire watershed to thinning to what was considered close to optimum density for timber production. As discussed in Baker (1986), most of the treated ponderosa pine watersheds had initial measured increases within the first year or two after treatment. However, within seven to ten years increases could no longer be detected. After the first two or three years increases could not be detected in water years well below the mean annual winter precipitation.

The method of research was the traditional paired watershed approach. Two adjacent or nearby watersheds are measured for several years and a pretreatment regression equation is obtained, i.e., water yield from the one to be treated is predicted from the one left untreated as a control. Following a calibration period of at least five to seven years, the test watershed is treated and the resulting runoff compared to the regression developed prior to treatment.

Two cases of potential increase are discussed – moderate thinning, as was done for Watershed 8, and very heavy thinning as was done on Watershed 17. Treatments for ecological restoration and forest health would likely be of a degree somewhere between these two. Charts presented are based on data available from the Beaver Creek website at the University of Arizona http://ag.arizona.edu/OALS/watershed/beaver/. Quantitative results are essentially the same as presented by Baker (1986).

Watershed 8 – Located in one of the highest water yielding areas of ponderosa pine in central Arizona, this 1800 acre watershed was thinned to 70 percent of its original density in 1974. In the 15 years prior to treatment the measured water yield ranged from a low of about 0.5 inches to a high of 23 inches, with a mean of 6.5 inches and a median of about 3.5 inches. Like other areas dependent on storm flow and snow melt without perennial base flow, a few very high years created a mean significantly higher than the median or point at which half of the years are above and below. Figures 13, 14, and 15 illustrate runoff and effects of treatment. Figure 13 illustrates the pretreatment regression line of Watershed 8 with its control, Watershed 13, and displays both pre- and post- treatment measurements. Figure 14 graphically shows the runoff -- both measured and the amount predicted from the pretreatment regression for all years, so that the relative magnitude of

Fig. 13. WS 8 (THINNED) vs WS 13 (CONTROL) RUNOFF

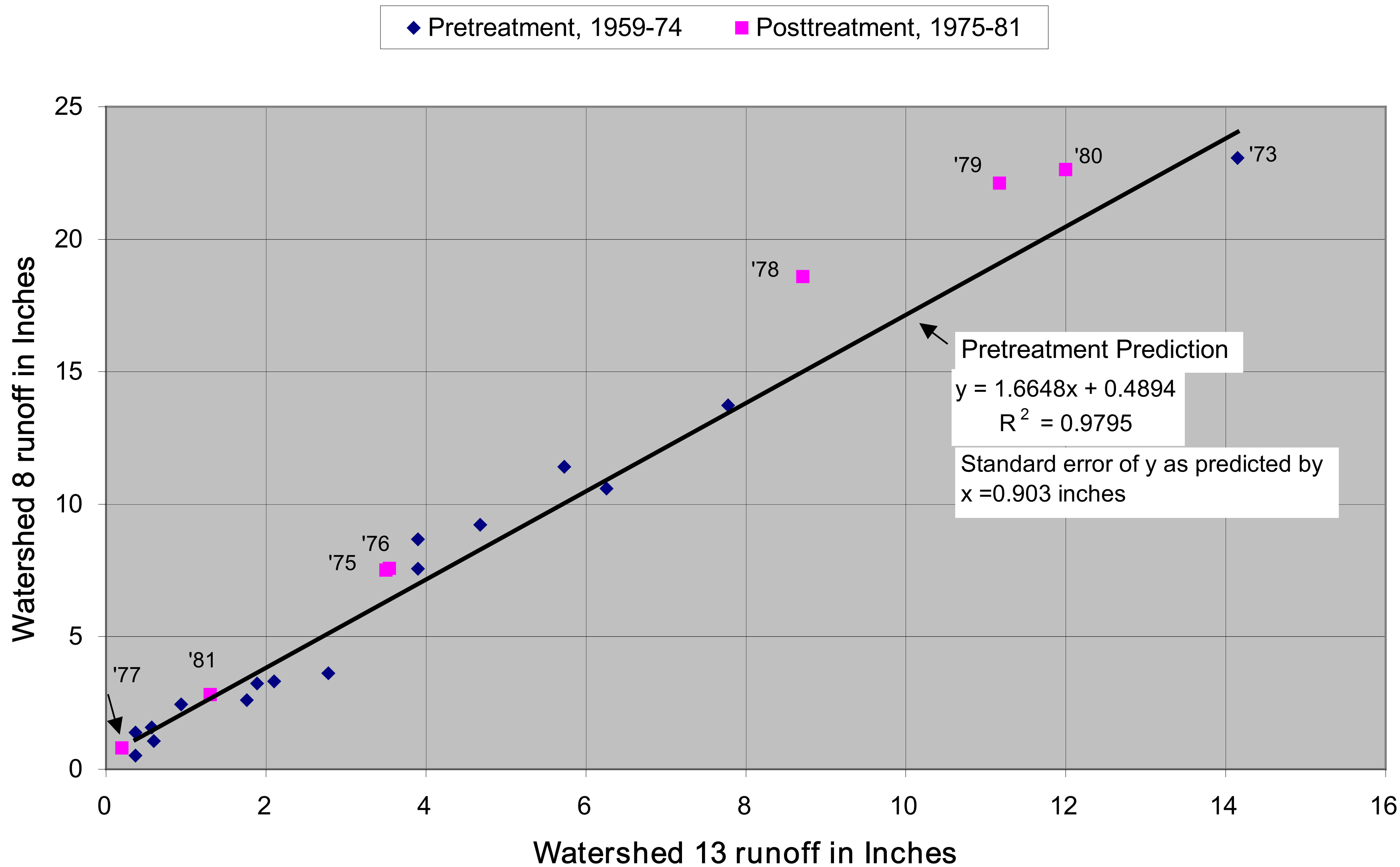


FIG. 14. BCWS 8 Predicted vs Measured Runoff, Water Years 1959-81

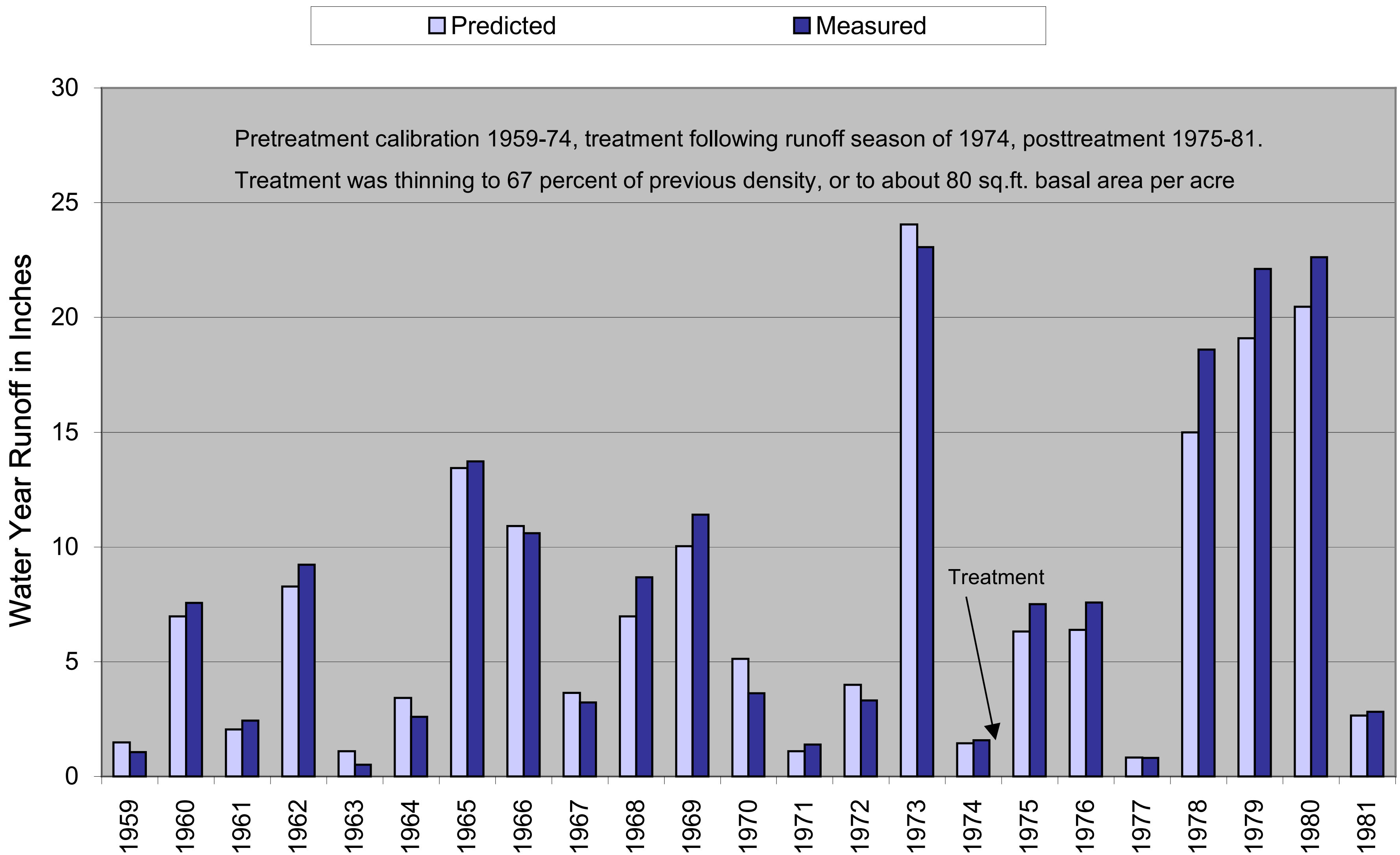
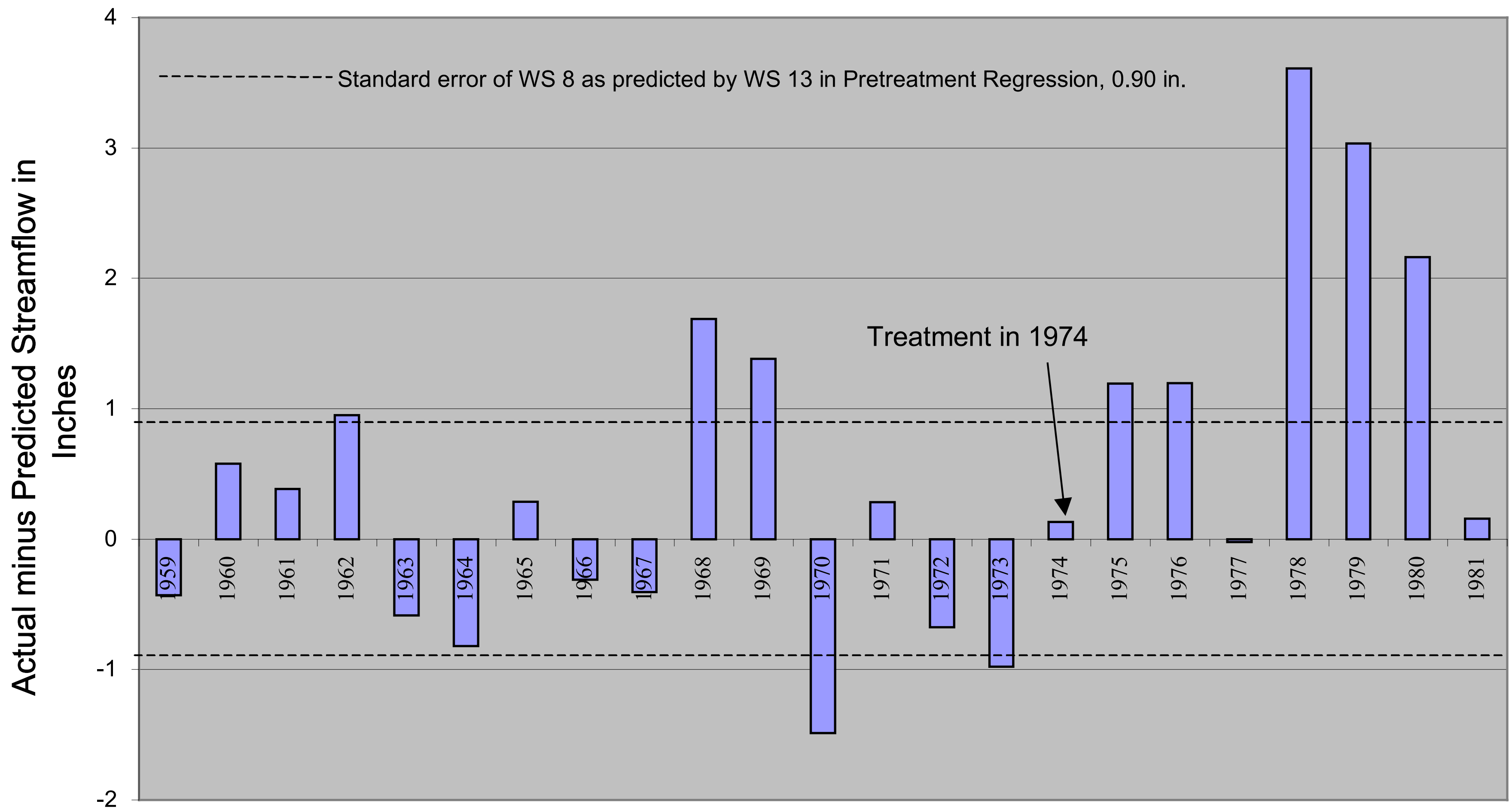


Fig. 15. Watershed 8 Streamflow Deviations from Pretreatment Regression with Watershed 13



differences can be observed. Figure 15 illustrates the deviations from the pretreatment regression - both before and after the treatment. The first two years after treatment had increases slightly greater than the standard error of the regression of prediction, the third year – the driest winter in the record – the yield was very slightly less than predicted. The fourth through sixth years were the three wettest consecutive winters in the record. In all three the water yield was significantly greater than pre-treatment regression. The seventh year had a very dry winter and there was no detectable increase.

Field review of watershed 8 in 2001 found that it has a varying tree density, having had a portion treated with a timber sale in the 1990's. Baker (1986) recommended that the highest potential for increasing measurable runoff might be on north facing slopes adjacent to stream channels. Such sites reviewed in the watershed were found to be fairly dense. Past thinning of ponderosa pine had resulted in stimulating the growth of Gambel oak and New Mexico locust, thus reducing potential water yield increase from pine thinning.

Watershed 17 - This watershed is also in a very high water yielding area, measuring slightly greater water yield than watershed 8 for years before either was treated. It was thinned to only about 25 percent of its original density, or a basal area of about 30 square feet per acre in 1969. Figures 16, 17, and 18 illustrate runoff and effects of treatment and are similar to the charts for Watershed 8. The first year after treatment there was a very pronounced increase, the second and third years were both below average in winter precipitation and runoff; however watershed 17 measured an increase greater than the standard error. The fourth year, 1973, was the wettest winter in the record and the watershed measured a 4.5 inch increase (25.3 inches of runoff versus 20.8 inches predicted). The fifth and eighth years were both very dry and there was no measurable increase. However, the sixth and seventh years had increases. The ninth, tenth and eleventh years were the 1978-80 series of extremely wet winters. In the first two there was a detected increase, but by the third year there was no detected increase. In the twelfth year, again a dry winter, there was no detected increase. (It should be noted that the two years with the biggest increase above the pretreatment regression were outside the range of data used in the regression.)

Recently the Northern Arizona University Institute of Ecological Restoration has included some evaluation of soil moisture in its ecological restoration experiments. Early evaluations in the first two years following thinning treatments at Fort Valley found increased soil moisture below the root zone in treated plots vs. controls (Kaye, et al 1999). This was following the winter moisture and did not occur from summer monsoon rains. One of these two years was an unusually dry winter, the other also below the long term mean for winter moisture. Unfortunately, subsequent years have not been analyzed.

In the Beaver Creek watersheds flow was measured as it passed through flumes as a result of rainstorms or snowmelt. It was considered to be surface runoff or interflow occurring at the interface of the forest litter layer and the soil. It is not known whether a significant portion infiltrated below the rooting zone and then passed laterally

Fig. 16. WS 17 (SEVERE THIN) vs 18 (CONTROL) RUNOFF

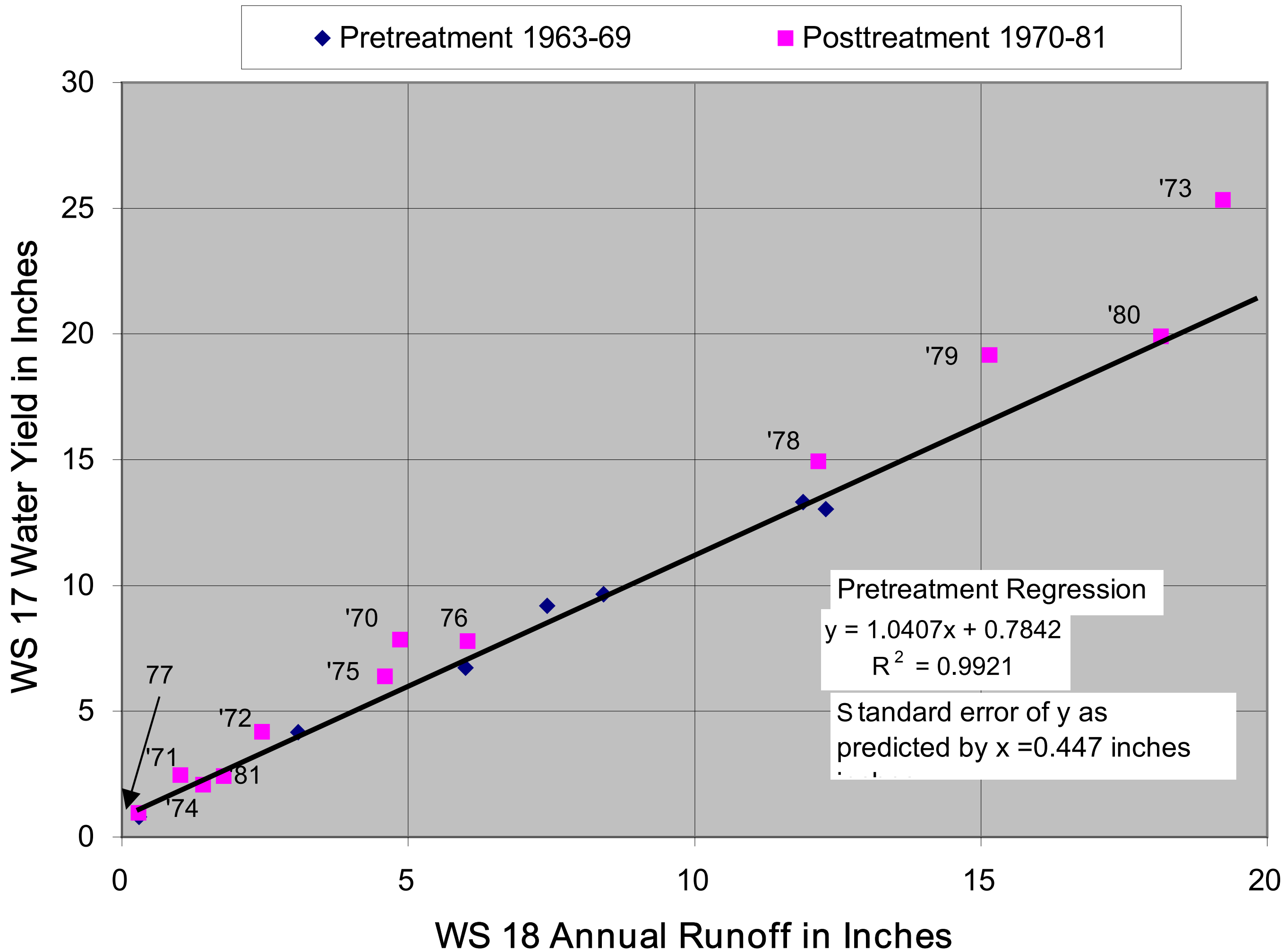


FIG. 17. BCWS 17 Predicted vs Measured Runoff, Water Years 1963-81

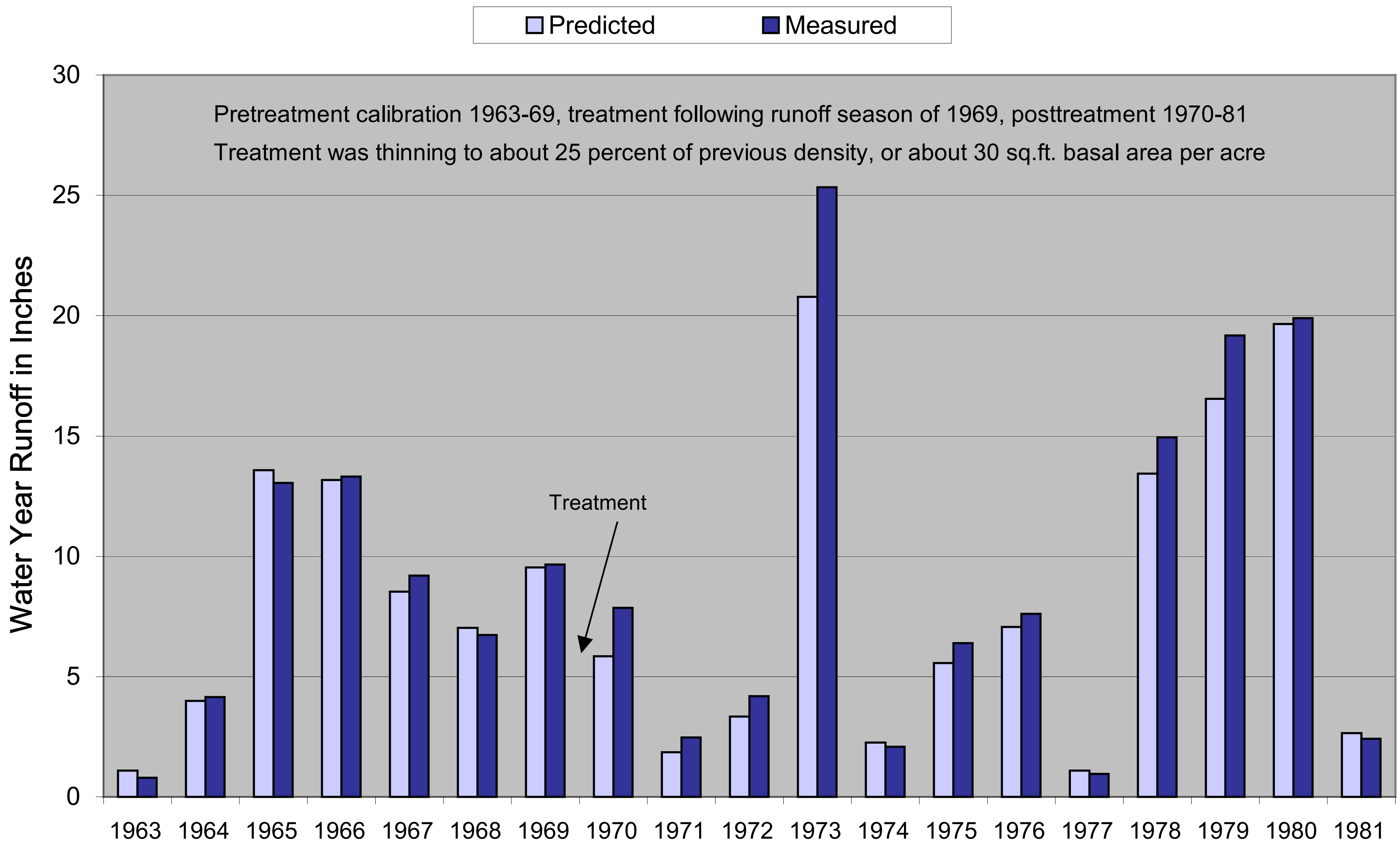
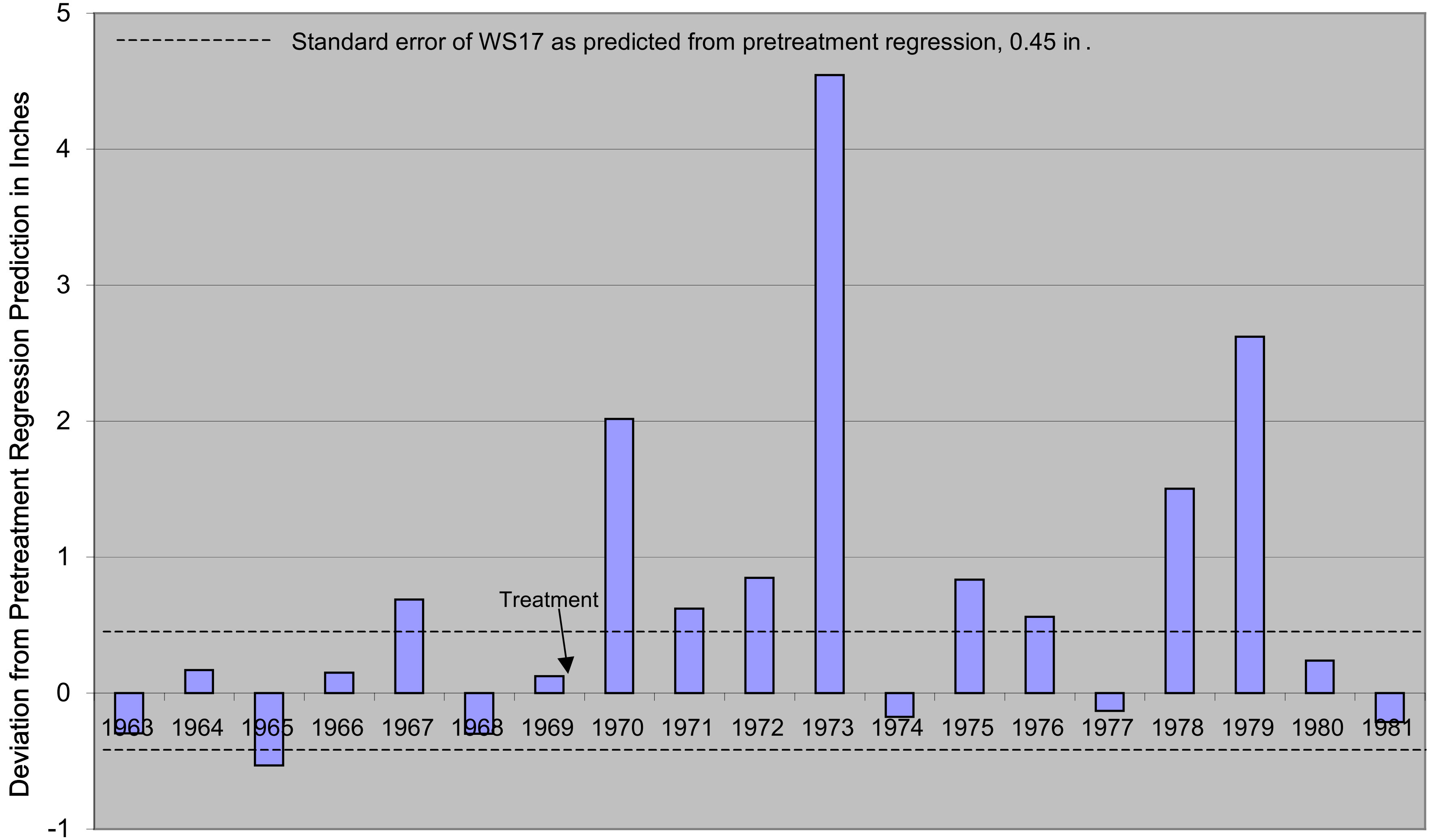


Fig. 18. Beaver Creek Watershed 17 Effects of Treament



downslope through the soil and surfaced in the channel above the flume. Thus, the excess flow through the root zone at Fort Valley might suggest a type of increase not measured at Beaver Creek.

It is known that some water flowing in channels in the Beaver Creek Experimental Watersheds was lost and did not continue through the flumes. Studies by Northern Arizona University geology students and staff documented some specific areas of loss along fault and/or fracture areas (Scholtz, 1969 and McCain, 1976). Whether this occurred in areas less obvious is not known.

Chaparral - At one time it was believed that there were significant opportunities for water yield increase via treating chaparral areas. Replacing the deep rooting shrubs with shallower rooted grasses and forbs was believed to have significant promise in the 1970's (e.g., Hibbert, et al, 1974). However, maintenance of treated areas was found to be impractical without use of herbicides, which have not been available for project scale use by federal agencies in a number of years. In addition, research has shown an initial flush of sediment and nutrients into local streamcourses until the chaparral vegetation is reestablished.

In the Santa Maria Mountains in the western portion of the watershed, Fuhrmann and Crews (2001) evaluated several methods of treating chaparral, in an area of transition with pinyon-juniper, to increase grass and other forage production. Herbicide treatment was the only one which precluded significant regrowth of shrubs two decades later. Fire and mechanical (pushing individual pinyon and juniper trees) treatments resulted in rapid regrowth of shrubs and trees.

More recently Baldys and Hjalmarson (1994) reported on conversion of chaparral by burning on the Tonto National Forest. For the first three years there was an increase in both water yield and sediment production; however, following these first three years the yield returned to preburn levels. Unlike studies in the ponderosa pine, they found that water yield increased by a greater percentage in dry vs. wet years, and in smaller vs. larger precipitation events.

Pinyon-Juniper Woodland - Studies at the Beaver Creek watershed found no measurable increase in runoff from pinyon-juniper treatment via chaining. An increase was measured as a result of aerial application of herbicides, but was not evident after the standing dead trees were removed. As stated for chaparral, aerial application of herbicides has not been an option available for National Forest management.

<u>Mid-level Analysis</u> – The information gained from the Beaver Creek Watershed program provided an opportunity to evaluate its effectiveness in correlation with larger areas. As Figure 26 shows, the Beaver Creek Watersheds are located within larger watersheds gaged by the USGS. By using annual (water year) streamflow measured in Utah juniper, alligator juniper, and ponderosa pine (both higher and lower elevation) a comparison was made to gaged flows in larger watersheds. Acres by general vegetative type were obtained from Coconino National Forest TES maps and watershed acreages.

Extrapolation of Beaver Creek Watershed streamflow measurements to larger watersheds having similar vegetative types and hydrologic response – no baseflow, highly responsive to storm events – resulted in close predictions with coefficient of determination, or R^2, of 0.97 to 0.98. For Rattlesnake Canyon, which includes a considerable amount of the smaller watersheds, the prediction equation was close to 1:1 (Figure 19). As the areas of prediction moved into watersheds with some base flow the prediction equation changed, i.e., the predicted watershed had a minimum annual flow (base flow) that it did not go below and it did not reach the same amount of areal runoff in the higher years. Figure 20, the correlation with Wet Beaver Creek illustrates this. Whether or not this difference is due to a greater portion of the precipitation going into groundwater recharge is not known. Groundwater is believed to be generally in a regional aquifer and streams have intersected it by incising into deep canyons.

Large Area Analysis – Watershed scale reconnaissance analysis was conducted using long term records for the Verde for an area slightly bigger than the Upper and Middle Verde watershed. Records for the Verde River began in 1888 and were taken at several locations over the years. Originally near Fort McDowell the site was moved upstream. The first dam, Bartlett, was constructed in 1939 and the second, Horseshoe, in 1945. The gage, Verde below Tangle Creek USGS No. 09508500, has been in place since 1945. An analysis comparing the Verde below Tangle Creek with Verde below Bartlett dam for the period since both were in place showed no significant difference (Fig. 21). Apparently any inflow from the intervening watershed was countered by evaporation and seepage at the two reservoirs. Although it would not be appropriate for comparison of high resolution, e.g., base flow, it was deemed appropriate for combining the two sets of records and developing a long term record indicative of the effects of climate and large scale watershed effects on flow. Figure 22 illustrates this flow.

The Barr Report of 1956 built a case on the declining relationship of streamflow to precipitation. Its area of analysis combined both the Salt and Verde basins and used the 40 year period of water years 1914-1953. It used a total of ten precipitation stations as an index of watershed precipitation. In order to look at just the Verde the stations within or adjacent to the Verde watershed were isolated. Of the ten stations four (Flagstaff, Jerome, Natural Bridge, and Prescott) are within or adjacent to the Verde watershed. Records at Natural Bridge, although dating back to 1891, ceased in the early 1970's. This left just Flagstaff, Jerome and Prescott so they were used for longer term comparison with Verde river flow.

Regression analysis of annual precipitation with Verde streamflow gave a poor fitting relationship which was improved considerably by confining it to winter precipitation (R^2 of 0.49 vs 0.79). Using the three station average of Prescott, Flagstaff and Jerome gave only a slight improvement over Prescott, alone. Figure 23 illustrates the relationship for

Fig. 19. Rattlesnake Canyon Measured Runoff vs. Predicted,
Water Years 1958-1980

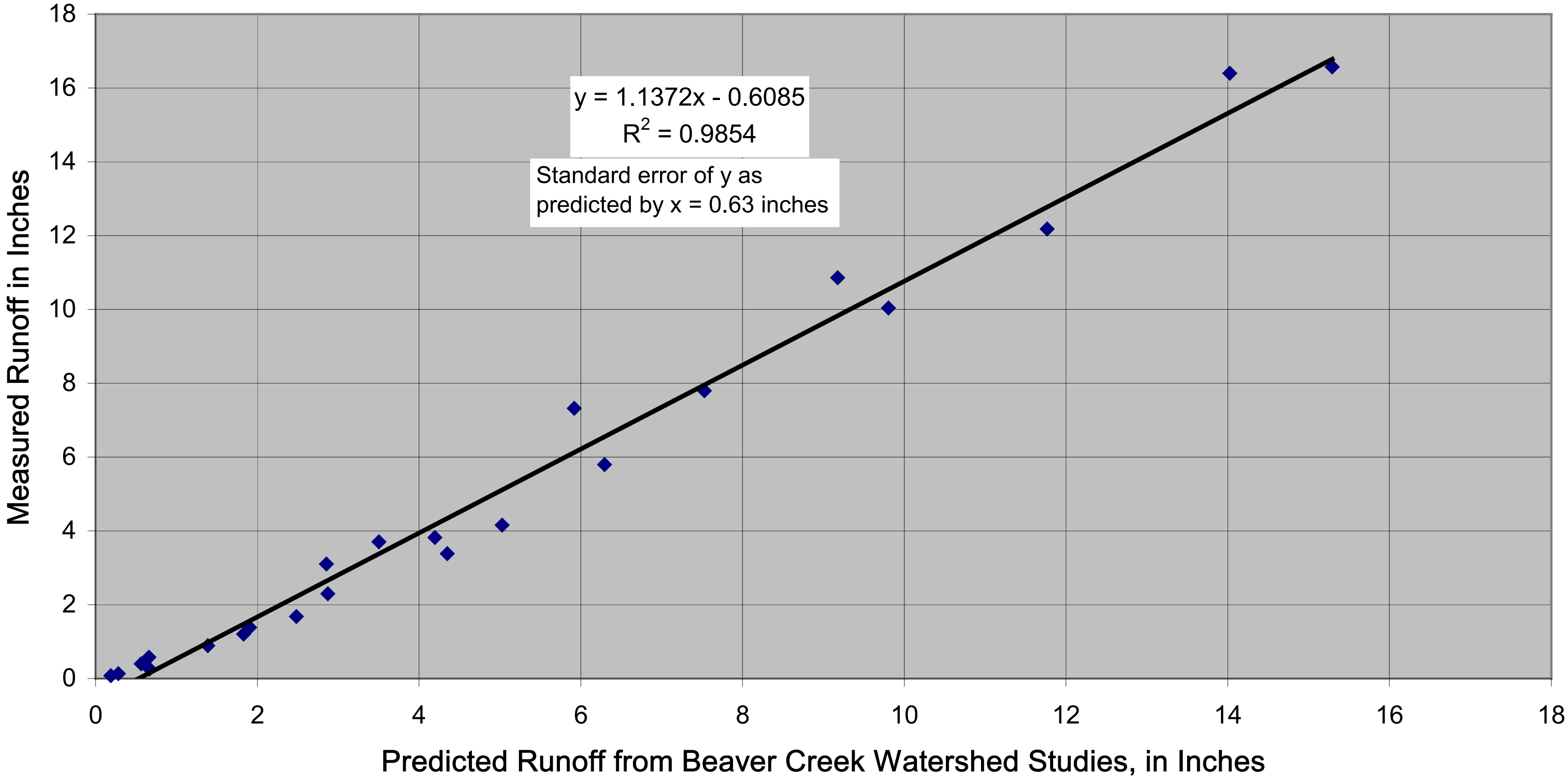


Fig. 20. Wet Beaver Measured vs Predicted, Water Years 1962-81

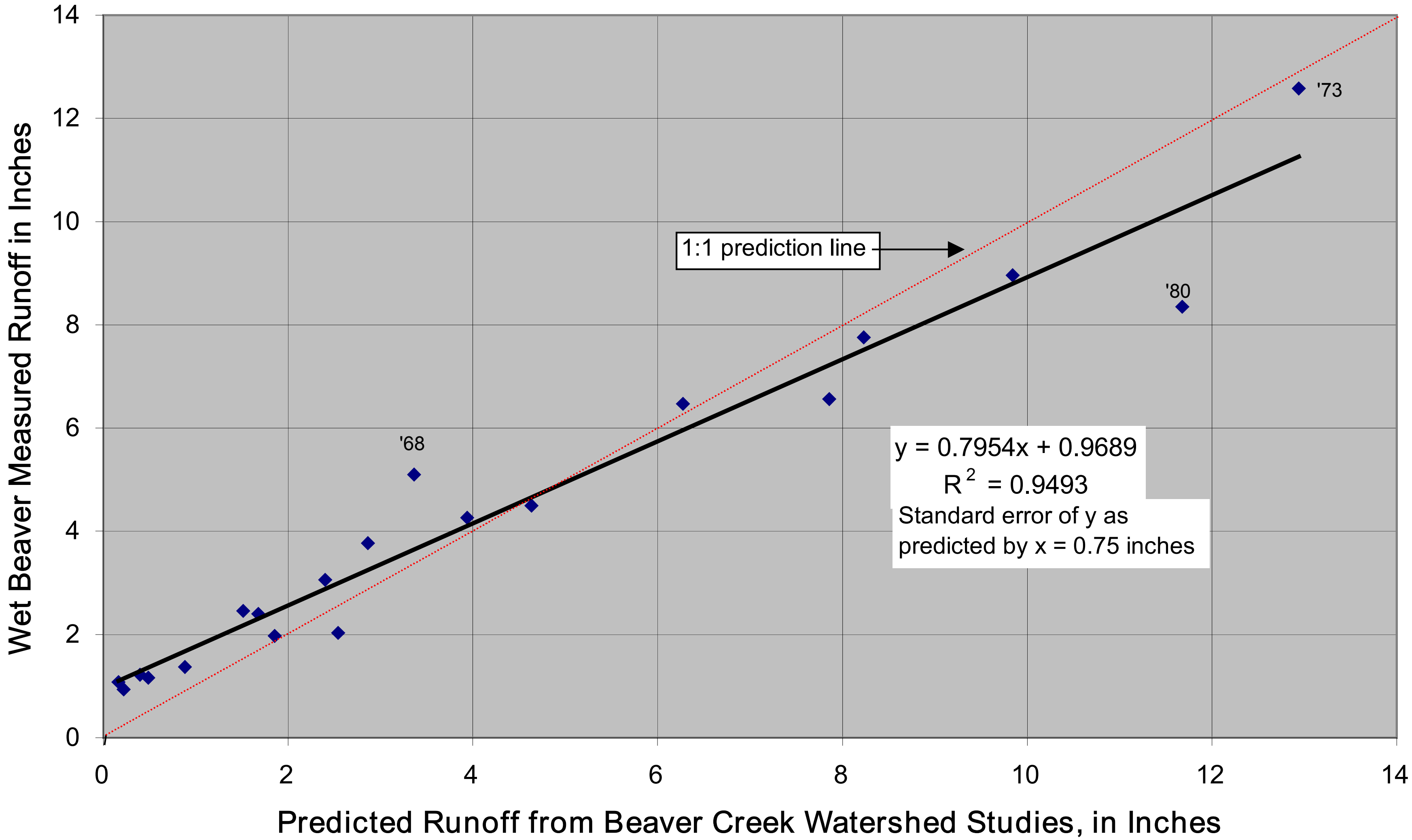
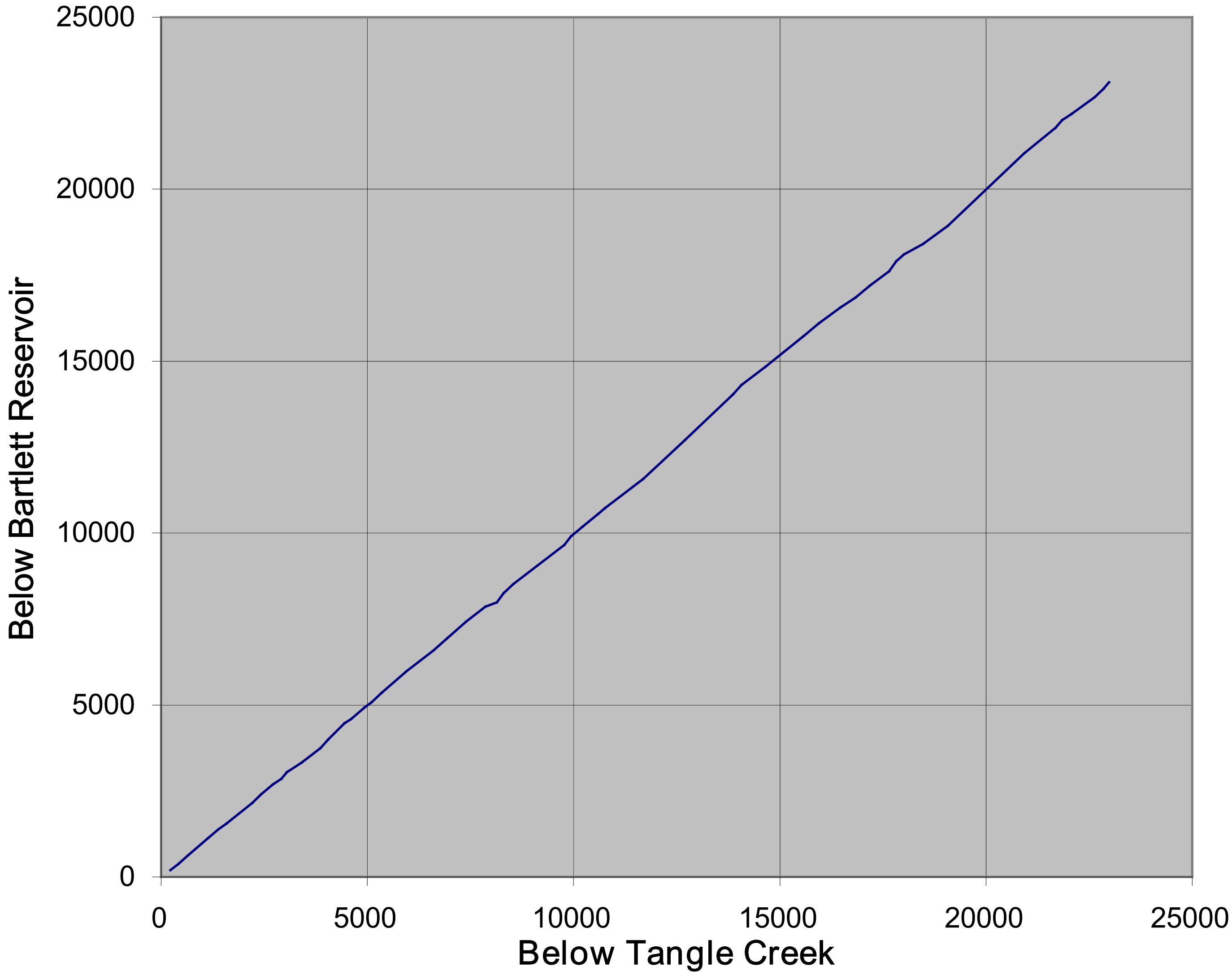


Fig. 21. Verde Cumulative Flow 1946-2000 in Thousand Acre-Feet



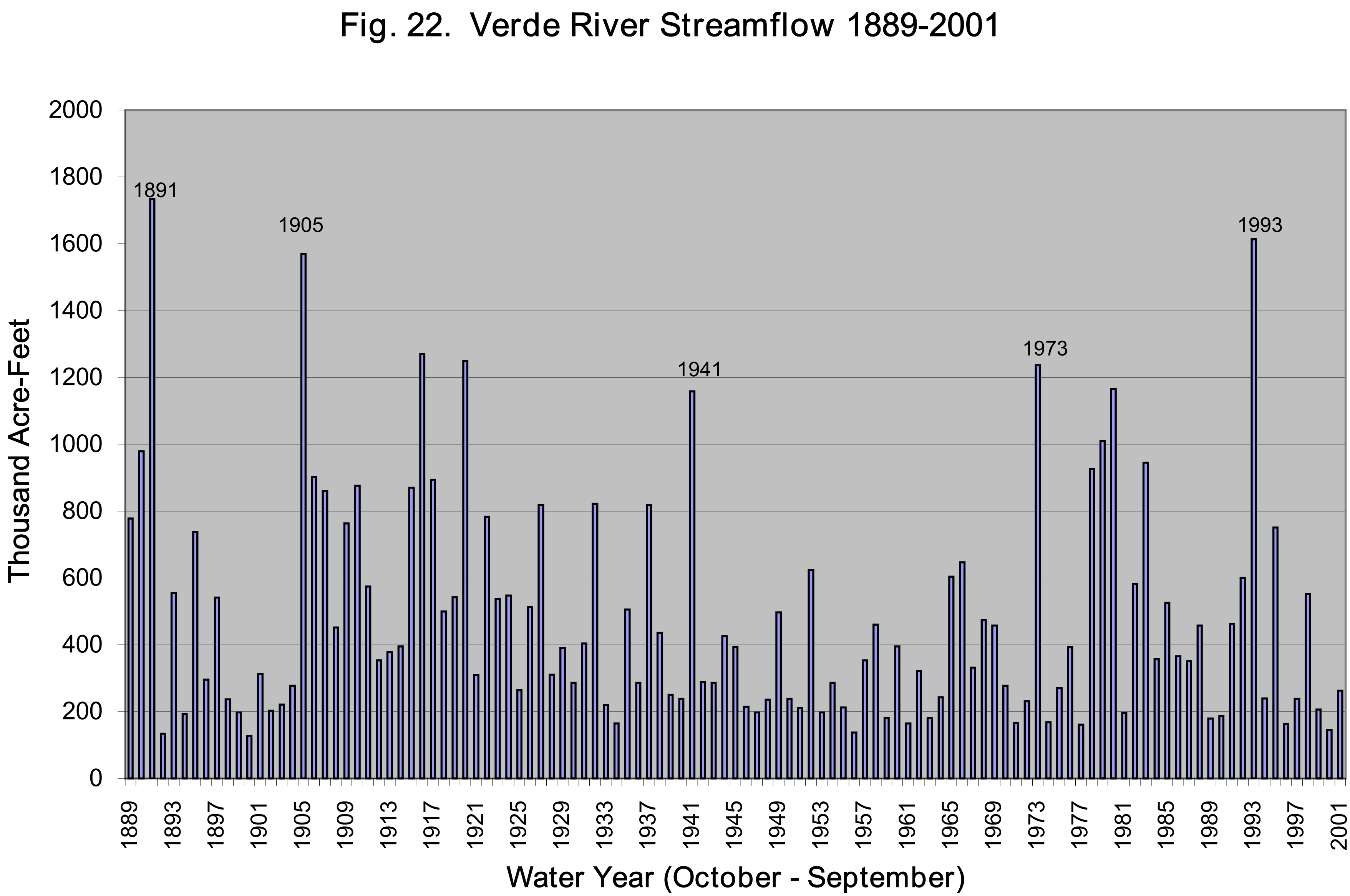


Fig. 22. Verde River Streamflow 1889-2001
Thousand Acre-Feet
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1891
1905
1941
1973
1993
1889
1893
1897
1901
1905
1909
1913
1917
1921
1925
1929
1933
1937
1941
1945
1949
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
Water Year (October - September)

Fig. 23. Verde Water Yield vs Winter Precipitation, WY 1914-53

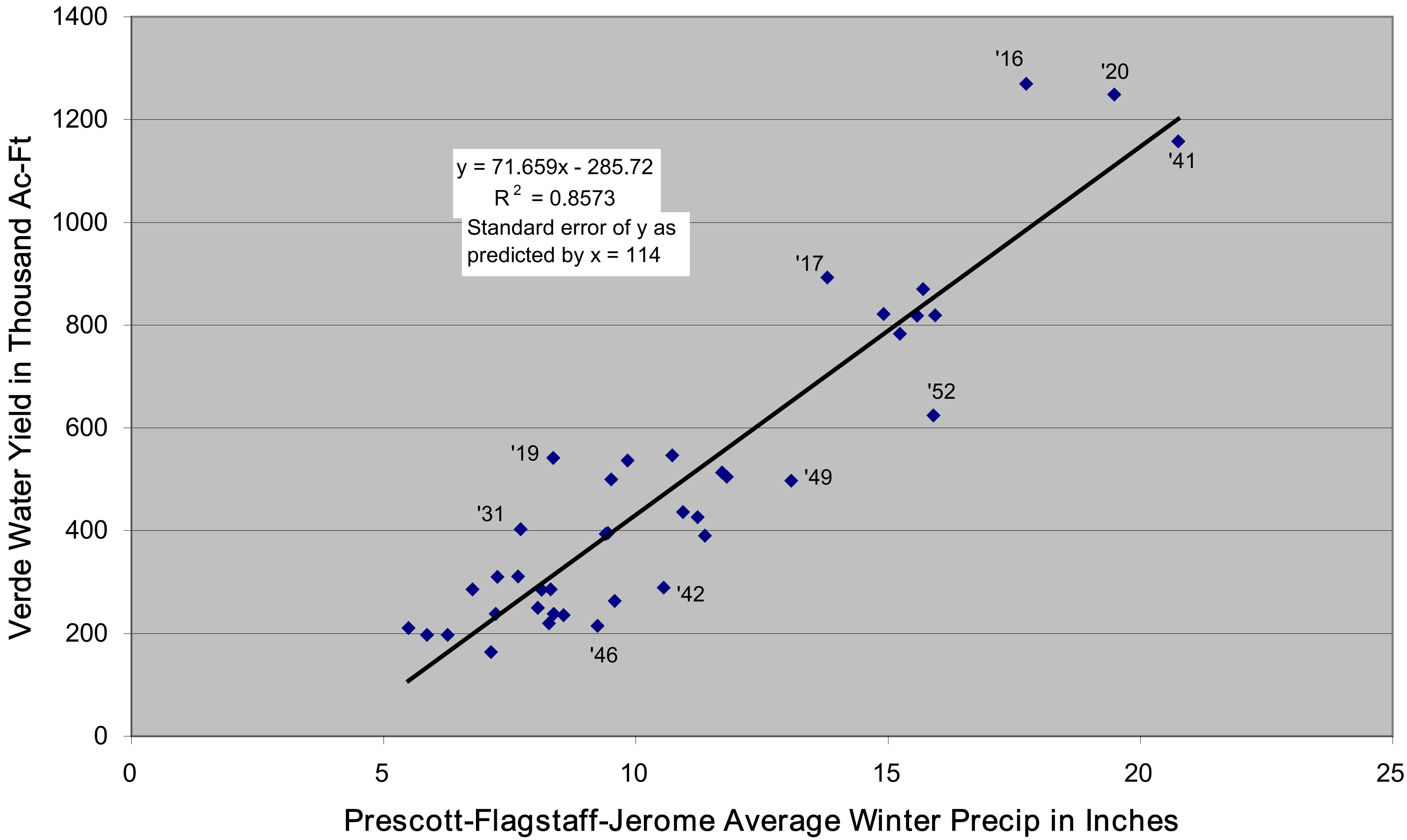


Fig. 24. Verde Water Yield vs Winter Precipitation, WY 1898-2001

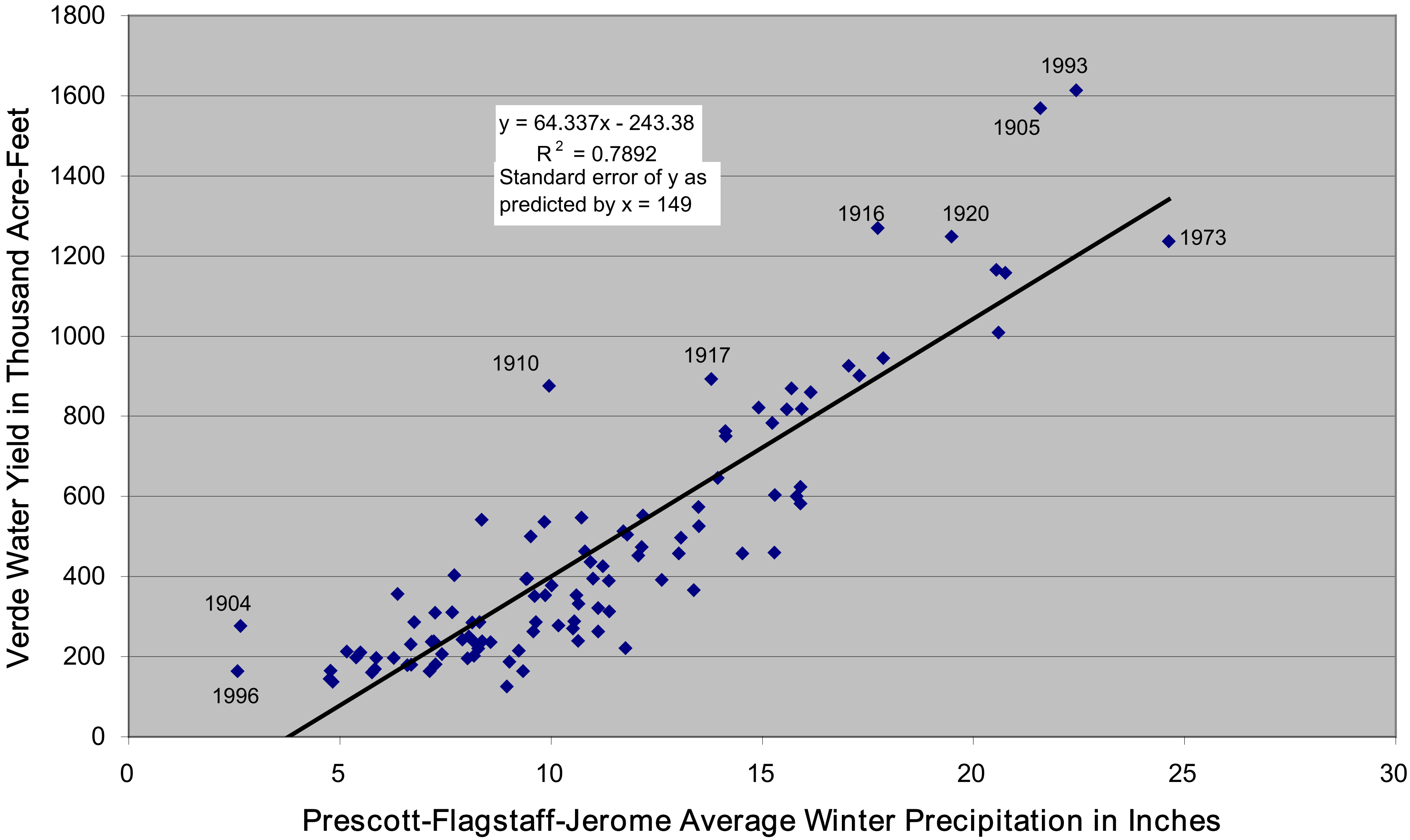
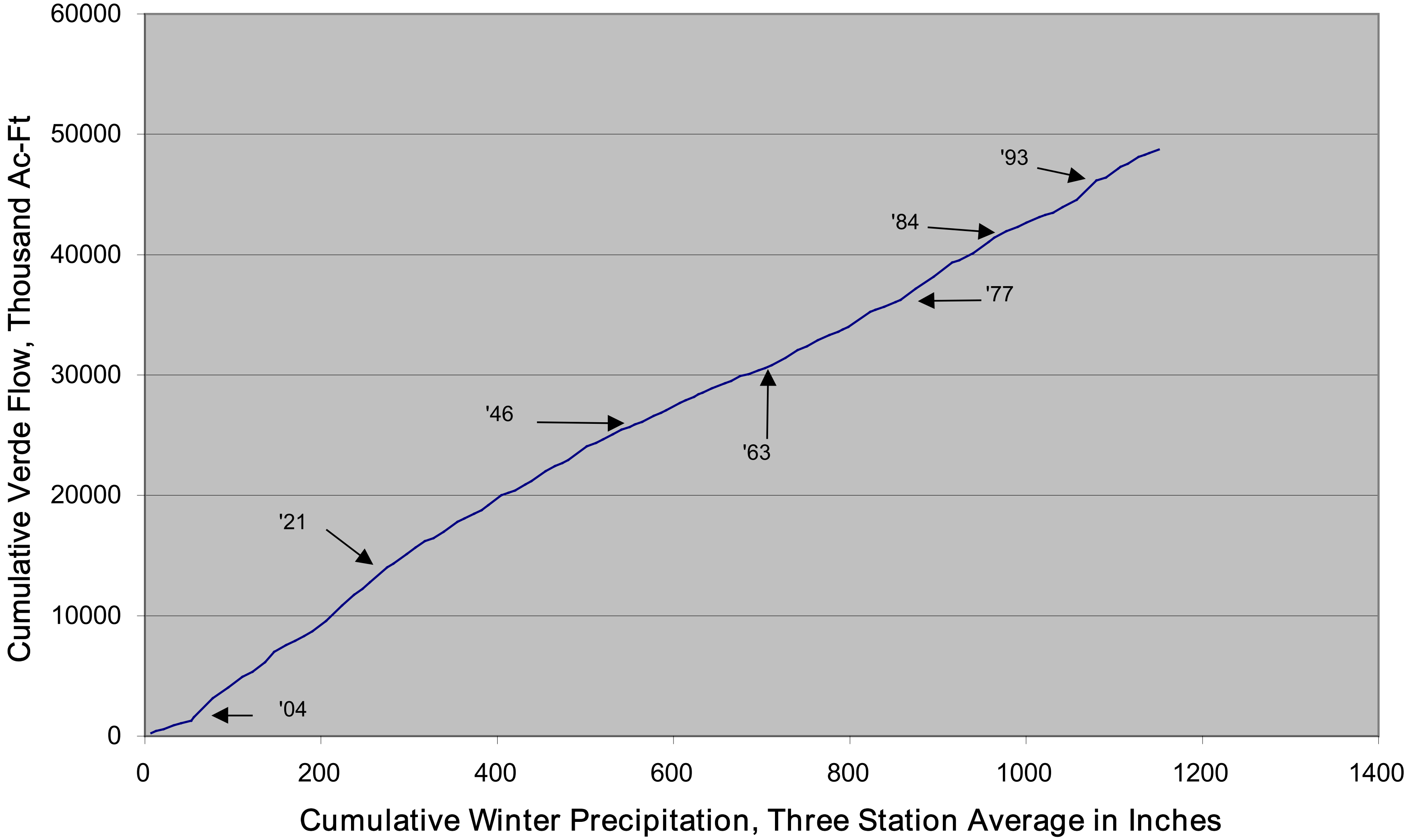


Fig. 25. Verde Cumulative Flow vs Winter Precipitation, WY 1898-2001



the period of the Barr Report, 1914-53, and Figure 24 illustrates it for the longer period of 1898-2001. In both figures it appears that earlier years produced more runoff for the same amount of winter precipitation. The one significant exception is 1993 when the pattern of storms produced major floods in both January and February, including the second highest recorded flood peak (the highest was in 1891, prior to precipitation data from Flagstaff and Jerome). The winter of 1993 produced the highest precipitation of the 104 year period for both Flagstaff and Jerome but was 15th at Prescott. Figure 24 also illustrates that the majority of the base flow of the Verde River is a result of flow from springs derived from long term storage accumulation, and has continued in years of minimal winter precipitation.

Comparing Figures 23 and 24, the relationship appears to be slightly steeper for the 40-year period of the Barr analysis than for the 104-year term extending through 2001, even though the winter precipitation averaged slightly more for the longer period (11.06 versus 10.82 inches). Figure 25 is a double mass plot of cumulative Verde River runoff versus cumulative winter precipitation. It illustrates some apparent changes in slope. However, the degree to which these might be affected by hydrologic conditions of the watershed versus meteorological conditions is unknown. The slope of the cumulative analysis plot will change with changes in general amounts of winter precipitation. In addition, there are some possible effects of changes in site locations of precipitation stations over the years that would need to be analyzed before reaching any conclusions.

One of the factors that must be kept in mind is the influence of the timing and pattern of winter precipitation. Concentration of a moderate total amount of precipitation into a short period of time may produce flooding and more runoff than the same amount of precipitation distributed more evenly over several months. More detailed analysis might be warranted.

Neary and Rinne (1997, 2001) discussed time trends of low flows on the Verde River and found upward trends at the Paulden and Clarkdale gages over a three decade period. They attributed this primarily to general increases in precipitation. Wirt and Hjalmarson (2000), in evaluating flow at the Paulden gage, emphasized reduced pumping in the portion of the Big Chino aquifer near the headwater springs.

F. Water Quality

The Arizona Department of Water Quality has assessed water quality periodically as a part of responsibilities under the Clean Water Act. Total Maximum Daily Load (TMDL) studies have been done for several segments of streams that had been classified as impaired. Among these have been nutrients and pathogens in portions of Oak Creek, nutrients in Peck's Lake, Stoneman Lake problems with eutrophication during dry periods, and turbidity in a segment of Beaver Creek. Draft TMDL studies have been conducted for both turbidity and nutrients in portions of the Verde River mainstem, e.g., Bowman, 2001. Recently there has been discussion of revising the turbidity standards to more adequately reflect the natural conditions in southwestern rivers subject to large variations in flow and episodic flushes of sediment into the stream systems. Because of the past and continuing work in water quality in much greater detail than this reconnaissance assessment, it was evaluated primarily as it might be affected by land uses or conditions in the sample subwatersheds.

One area identified as needing further inventory and analysis was the effect of rapid urbanization of areas near the Verde River and perennial tributaries, especially Oak Creek, Beaver Creek, and West Clear Creek. Besides potential effects on sediment and turbidity, the impacts of storm runoff flushing contaminants from streets, parking lots, and commercial and industrial areas are an unknown.

Though of a generally shorter duration, the potential impact of large, very hot wildfires on water quality is a danger. Flushes of ash and sediment may cause adverse affects on aquatic biota. However, a real long-term watershed danger is the potential for soil damage through removal of organic matter, loss of surface layer and changes to surface soil structure that result in reduced infiltration and overall lowered site productivity. The 1977 Radio Fire on steep slopes on the outskirts of Flagstaff is an example as are several more recent fires such as the 2000 Pumpkin Fire on Kendrick Mountain. Although outside the Verde watershed, the ecosystems and soils are similar to many within it.

G. Riparian

Like water quality, riparian areas have been given a priority for inventory and analysis by both state and federal agencies and, because of the degree of detail and emphases by these agencies, they were evaluated in this assessment as relevant to the sample subwatersheds. In addition to several types and protocols for inventories, federal land management agencies are using the Proper Function and Condition (PFC) process for a broad level assessment. The PFC provides a basis for prioritizing and identifying where more quantitative information is needed.

IV. CONCLUSIONS AND OPPORTUNITIES

1. There was not found a consistent and uniform methodology and/or inventory system for evaluating watershed condition. The evolving procedures by the Forest Service, especially those used by the Prescott National Forest in conjunction with Verde River habitat evaluation, were the most comprehensive and documented. There is a need for interagency agreement on basic data collection, analysis and classification procedures and protocols for evaluating condition of both upland watershed conditions and riparian/aquatic functions. The procedures should be repeatable, defensible & documented, and capable of data storage and analysis. Participants should include both federal and state agencies including BLM, Forest Service, USGS Biological Survey, US Fish & Wildlife Service, Arizona Department of Environmental Quality, and Arizona Game & Fish Department, as well as Arizona universities and nongovernmental entities with expertise such as The Nature Conservancy. This recommendation is broader than just the Verde watershed and is applicable statewide and possibly regionwide.
This assessment started out to use the joint BLM and Forest Service procedure, A Framework for Analyzing the Hydrologic Condition of Watersheds. June, 1998. USDA Forest Service and USDI Bureau of Land Management. BLM Technical Note 405. However, it was not found to be practical for this application.

In addition there is a need for interagency consistency in inventories in terms of characteristics affecting watershed function and condition. Inclusion of soil hydrologic interpretations in Forest Service Terrestrial Ecosytem Survey reports would be a significant enhancement and is recommended. This information is currently included in Natural Resource Conservation Service soil surveys. There is a need for evaluation of the soil hydrologic group system and its use in order to achieve better consistency, as well as finer resolution.

2. Analysis of time trends found considerable variation in year to year and decade to decade reported ground cover in the pinyon-juniper and desert shrub communities. A significant amount of this is due to weather. Management activities, especially as related to livestock grazing, have also had some effects. Another factor is the uncertainties and inconsistencies of sampling and measuring techniques over time.

3. Within the pinyon-juniper and desert shrub communities there is a varying degree of difference between current conditions and what the sites are capable of providing in terms of soil protective cover and opportunity for rainfall infiltration. Historic and, to some degree, continuing land uses have added to the natural effects of climatic variation resulting in areas where hydrologic function does not meet land management objectives. The degree and "irreversibility" of impact vary, with geologic formation appearing to be one important factor. Analysis indicated that some small watersheds are producing more runoff from rainstorms, resulting in more frequent flows of a given magnitude and consequent impacts to channels. The techniques used for comparison produced results which were consistent with observed effects on ephemeral stream channels.

4. There are opportunities for enhancement of on-site productivity and hydrologic function in the pinyon-juniper and desert shrub communities. They vary in potential and likelihood of success. A program of analysis, application, evaluation and adaptation is recommended. Some effort in this manner was observed on the Prescott National Forest.

5. Urbanization has varying effects on storm runoff and impacts on channels depending on the hydrologic character of the soils, type and character of development, and configuration of impervious versus absorptive surfaces. There are opportunities to reduce the impacts of development. However, some of the most common, e.g., turf, have effects of increasing water use in an area with shortages of water.

6. The effects of urbanization on water quality are not adequately known. With the rapid urbanization, especially near stream courses, an evaluation of the effects and appropriate amelioration is needed.

7. Widespread opportunities for increased water yield through vegetation management were not identified. This is especially the case for periods of average or lower precipitation. However, there appears to be a potential for a slight increase as a corollary to applications of ecological restoration treatments being initiated on a trial basis and proposed on a much wider scale. An evaluation of the effects – both on and off site—is needed. The experiments by the NAU Ecological Restoration Institute seem to be a logical first step. Continuation of earlier soil moisture evaluation is recommended.

8. In addition to the possible corollary benefits of some increased water yield, judicious applications of ecological restoration treatments should reduce the likelihood of short term effects to water quality and long-term site specific effects to hydrologic function from stand replacing wildfires.

V. INVENTORY UPDATE

One of the deliverables of this project is an update of inventories and databases to supplement that included in the 1996 Verde Cooperative River Basin Study. That report contains a number of GIS coverages, described on pages 3-8 with a number of the maps displayed in Appendix B. They can be accessed via internet at:
http://www.verde.org/covers.html

A number of the Cooperative River Basin Study (CRBS) GIS coverages were extracted from the Arizona Land Resource Information System (ALRIS) maintained by the Arizona State Land Department.

For each GIS coverage the ALRIS site provides metadata, or "data about data", giving available information regarding the inventory, its source, its scale of mapping, the date of mapping, and other relevant factors.

The ALRIS home page with a general description is available at:
http://www.land.state.az.us/alris/htmls/data2.html

The individual GIS coverages, including descriptions and metadata are available at:
http://www.land.state.az.us/alris/index.html

The following is a supplement to the CRBS, arranged in the same sequence. It includes databases and information sources in addition to those which are in GIS coverages.

A. Soils and Geology

Soils – The statewide soils coverage in ALRIS is from the Natural Resources Conservation Service (NRCS) and is primarily at a scale of 1:250,000. There are two other sources for soils inventories.

Soil Surveys by USDA Natural Resources Conservation Service (NRCS), formerly Soil Conservation Service in cooperation with Arizona Agricultural Experiment Station. Soil classification is to the series level. Productivity ratings and interpretations for use and management are given. Include descriptions of representative soil profiles. Displayed on orthophoto map sheets. Available from the NRCS. Some are digitized for GIS.

Yavapai County, Arizona, Western Part. 1976. Scale 1:31,680. Located in northwest portion of watershed including Big Chino north to Coconino County line. Includes west division of Prescott National Forest with participation by Forest Service.

Coconino County, Central Part. 1993. Scale 1:31,680. Located in northwest portion of watershed in Coconino County. Available both as published report and is digitized in GIS.

Black Hills – Sedona Area, Arizona, Private and State Land Part. Undated. Scale 1:24,000. Private and State Trust lands in Verde Valley including Sedona, Cottonwood-Clarkdale, and Camp Verde.

Beaver Creek Area. 1967. Scale 1:31,680. Wet and Dry Beaver Creek Watersheds. To soil series level. Includes hydrologic interpretations. Done in cooperation with Forest Service.

Long Valley Area. 1974. Scale 1:31,680. Portion of Coconino National Forest south and southeast of Beaver Creek Area survey. Similar to Beaver Creek Area report.

<u>Terrestrial Ecosystem Surveys for Kaibab, Coconino, and Prescott National Forests</u>. USDA Forest Service, Southwestern Region. Scale 1:24,000. Soil classification to family level. Productivity ratings and interpretations for use and management are given. Does not include descriptions of soil profiles. Detail of interpretations and ratings evolved over time and thus some differences between individual National Forests. Interpretations related to soil hydrologic function not included in reports. Digitized and printed overlaying USGS 7.5 minute topographic maps.

Kaibab National Forest, Williams, Arizona. Field work completed 1986.
Coconino National Forest. Flagstaff, Arizona. Field work completed 1991.
Prescott National Forest, Prescott, Arizona. Field work completed 1997.

Geology - The statewide geology map in ALRIS is at a scale of 1:1,000,000. Other maps include:

Geologic Map of Yavapai County. 1958. Prepared by Arizona Bureau of Mines and University of Arizona. 1:375,000. Available from Arizona Geological Survey, Tucson.

Geologic Map of Coconino County. 1960. Prepared by Arizona Bureau of Mines and University of Arizona. 1:375,000. Available from Arizona Geological Survey, Tucson

There are numerous other published geology maps for portions of the watershed, including several areas at a scale of 1:100,000. The U.S. Geological Survey is in process in summer 2002 of compiling and digitizing 1:100,000 coverage for the upper and middle Verde watersheds.

B. Water Resources Coverages
1) <u>Precipitation</u> - Table 10 displays precipitation stations within the watershed that are contained in the major databases, as well as internet links to access data.

TABLE 10. VERDE WATERSHED PRECIPITATION GAGES (within and adjacent to watershed)

GAGE	Elevation	Period of Record water years	Missing or incomplete water years
Ash Fork	5140-5210	1913-73	1914,15,29 incomplete
Beaver Ck RS	3820	1959-2001	1994,96,98 incomplete
Beaver Creek Watersheds[2]	5000 to 7600	1958-1982	
Camp Verde	3100	1870-1890	
Camp Wood	5720	1943-78	
Childs	2650	1916-2001	1919 & 1924 incomplete
Chino Valley	4750	1942-2001	1996 incomplete
Drake RS	4650	1916-61	1926 & 27 incomplete
Flagstaff	6920	1898-1949	
Flagstaff Airport[3]	7000	1951-2001	
Fossil Springs	4270	1936-1970	
Fort Valley	7350	1910-2001	1994 &1995 incomplete
Happy Jack RS	7480	1970-2001	1997 incomplete
Irving	3760-3800	1936-1997	
Junipine	5120	1936-81	1941-43, 46-47, 50 incomplete
Oak Creek Canyon[4]	5080	1983-2001	1987 & 88 incomplete
Jerome	5250-4950	1898-2001	1900,17-19,66-67,86-88 incomplete
Montezuma Castle	3180	1939-2001	
Prescott	5520-5210	1870-2001	1873,1875,1907,45,98 incomplete
Rimrock	3600	1943-61	
Sedona Ranger Sta	4220	1945-2001	
Seligman	5220-5250	1906-2001	1908,10-12,15,17,22-23,36-38, 45-47,74-75,87 incomplete
Seligman 13SSW	5240	1963-81	
Tuzigoot	3470	1921-36, 1950-2001	1936,95 incomplete
Walnut Creek RS	5160-5090	1917-2001	1929,35,37 incomplete
Williams	6750	1904-2001	1906,08,11,47,48 incomplete
Yaeger Canyon	6000	1919-20, 1926-46	1944 incomplete

Records through April 1998 from University of Arizona weather records http://ag2.calsnet.arizona.edu/cgi-bin/weather.cgi,
For the period May 1998-Sept 2001 from Arizona Climate Summaries, http://www.wrcc.dri.edu/summary/climsmaz.html Records are rearranged to display by water year (October – September) rather than calendar year. First year shown in period of record is first year with complete water year, and last year is last year with complete water year. Years shown as incomplete have one or months with enough days missing that no record is shown in the Arizona climate records.

[2] Beaver Creek Experimental Watersheds. A total of 64 precipitation gages distributed across area, with many for the full data period and some for partial. Map and general description available at http://ag.arizona.edu/OALS/watershed/beaver/precipitation.html
Data available on line at http://great-sandy.arid.arizona.edu/beavercreek/datarequest.asp

[3] Records for Flagstaff and Flagstaff Airport overlap so that WY 1950 can be completed using a combination of the two.

[4] Oak Creek Canyon located near former Junipine gage site.

Precipitation records and information is available from several sources. The National Weather Service Office in Phoenix contains current information and forecasts and can be reached at: http://www.phx.noaa.gov/

The Western Regional Climate Center has a database for Arizona with extensive precipitation and temperature data and statistics at: http://www.wrcc.dri.edu/summary/climsmaz.html. This site contains both long term and 30 year (1961-90 and 1971-2000) averages for daily, monthly, and yearly precipitation, along with extremes.

The Arizona Weather site maintained by the University of Arizona in cooperation with the National Climatic Center at Asheville, NC contains some precipitation data not found in the previous listing. It is accessed at: http://ag2.calsnet.arizona.edu/cgi-bin/weather.cgi

For most comprehensive analysis of historical weather a combination of the two above sites is recommended.

Yavapai County Flood Control has a network of both recording and regular rain gages operated by volunteers which supplements the system of Cooperative Weather Stations managed and reported by the National Weather Service.

The Salt River Project also maintains a network of precipitation gages to fill in areas not covered in the National Weather Service network within the Verde watershed.

2) Streamflow – Table 11 and Figure 26 display streamgages and the watersheds they gage. Figure 27 displays period of record for streamgages displayed on same time scale as long time trend of Verde River streamflow.

Data for the USGS streamgages, both current and former, is available through the USGS Arizona Water website: http://az.water.usgs.gov/
The current active stream gages can be accessed via real time coverage as follows:

Go to real time stream flow at http://az.waterdata.usgs.gov/nwis/current/?type=flow then scroll down to Verde River Basin. Records for the various stream gages can then be accessed. Historic information can also be accessed for these gages through this website. Historic information on gages which have been closed can be accessed using the site number from Table 11, beginning with 095 and using all eight digits.

Statistical information on streamflow, including peak flows and low flows, through water year 1996 for USGS gages is available through Water Resources Investigations Report 98-4225 by Pope, et al, cited in the bibliography.

3) – Data for water quality collected by the USGS at their stream gage sites is available through the water website, http://az.water.usgs.gov/ and is an option that can be selected.

Table 11. Stream Gages in Upper and Middle Verde Watershed and on Verde River Mainstem				
Name	**USGS No. 095____**	**Drainage size Sq miles**	**Period of Record**	**Comments**
Williamson Valley nr Paulden	2800	255	Apr 1965-Sep 1985, Sep 2001-present	
Del Rio Springs nr Chino Valley	2900	40.9	Oct 1996-present	Within Prescott Active Management Area
Granite Ck @ Prescott	2960	30	Dec 1994-present	Within Prescott Active Management Area
Granite Ck nr Prescott	3000	36.3	Jul 1931-Sep 1947, Oct 1995-present	Within Prescott Active Management Area
Walnut Creek	2750	36	Oct 1991-Sep 1992	Bureau of Reclamation
Verde River nr Paulden	3700	2,150	Aug 1963-present	
Hell Canyon nr Williams	3720	14.9	Aug 1965-Sep 1972	
Verde River nr Clarkdale	4000	3,124	Jul 1915-Oct 1916, Jun 1917-Jun 1921, May 1965-present	
Oak Cr nr Sedona	4420	233	Oct 1981-present	station moved
Oak Cr nr Cornville	4500	355	Jul 1940-Sep 1945, May 1948-present	
Wet Beaver Ck nr Rimrock	5200	111	Oct 1961-Oct 1982, Oct 1989-present	misc mo's in 1985, 86 & 87 missing
Rocky Gulch nr Rimrock	5220	1.4	Oct 1985-Sep 1992	Also, Oct 1958-Sep 1981 by Forest Service
Red Tank Draw nr Rimrock	5250	48	May 1957-Sep 1978	
Rattlesnake Can nr Rimrock	5300	24.6	Jul 1957- Sep 1980	
Dry Beaver Ck nr Rimrock	5350	142	Oct 1961-present	
West Clear Ck nr Camp Vrde	5800	241	Jan 1965-present	
Verde River nr Camp Verde	6000	4,645	Apr 1934-Sep 1945, Oct 1988-Sep 1994, Oct 1997-present	
Verde River below Tangle Ck	8500	5,494	Aug 1945-present	above reservoirs
Verde River below Bartlett Dam	10000		Jan 1904-Dec 1910 Oct 1913-present	Bartlett & Horseshoe dams constructed 1939 and 1945
Beaver Creek Watershed small watersheds	*	0.1 to 2.8	Oct 1957-Sep 1981	Eighteen gaged watersheds, some for less than full period of record
Woods and Bar M Watersheds	*	18.9 & 25.6	Oct. 1961-Sep 1983	

*U.S. Forest Service, Rocky Mountain Forest & Range Experiment Station

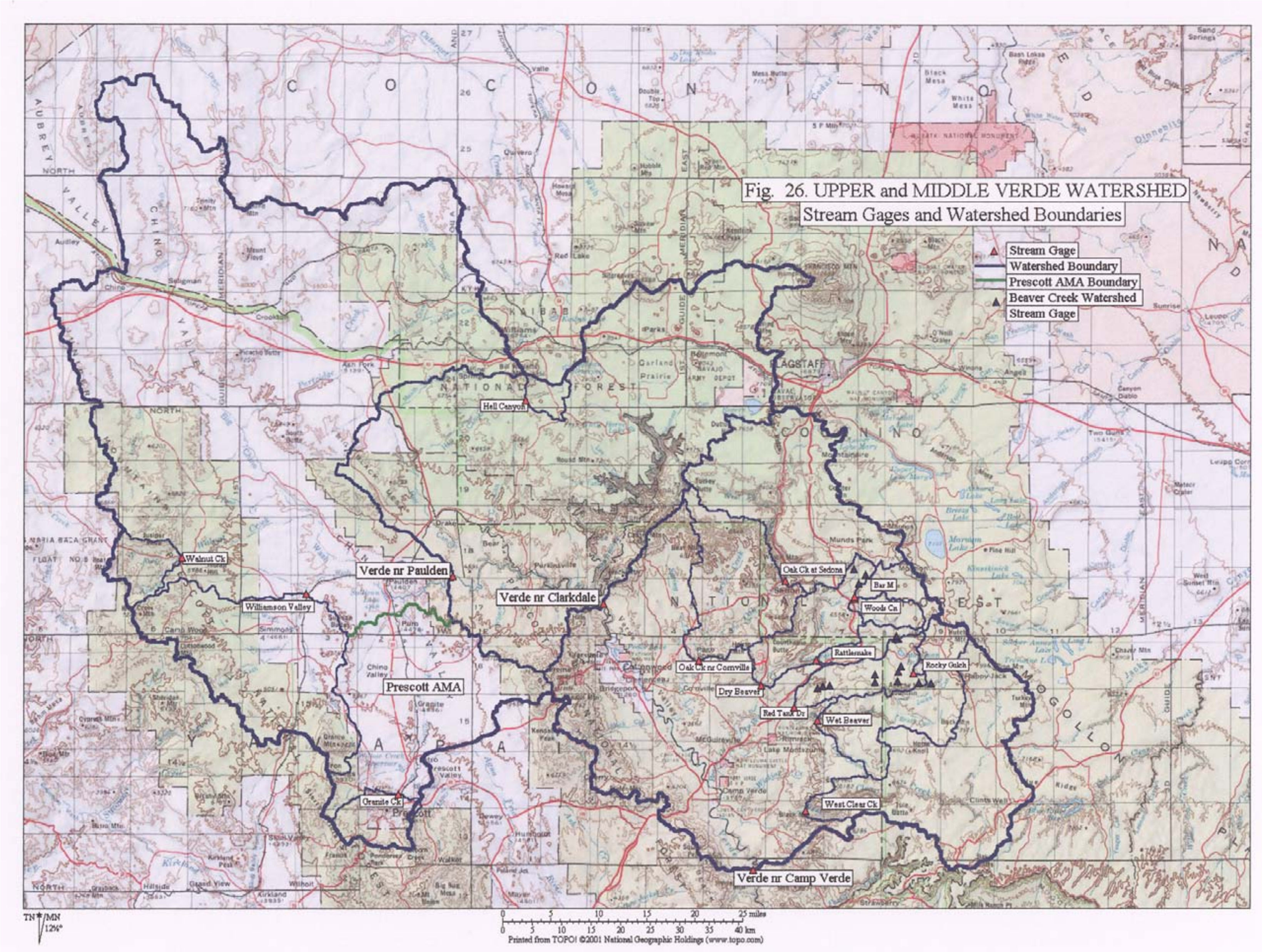
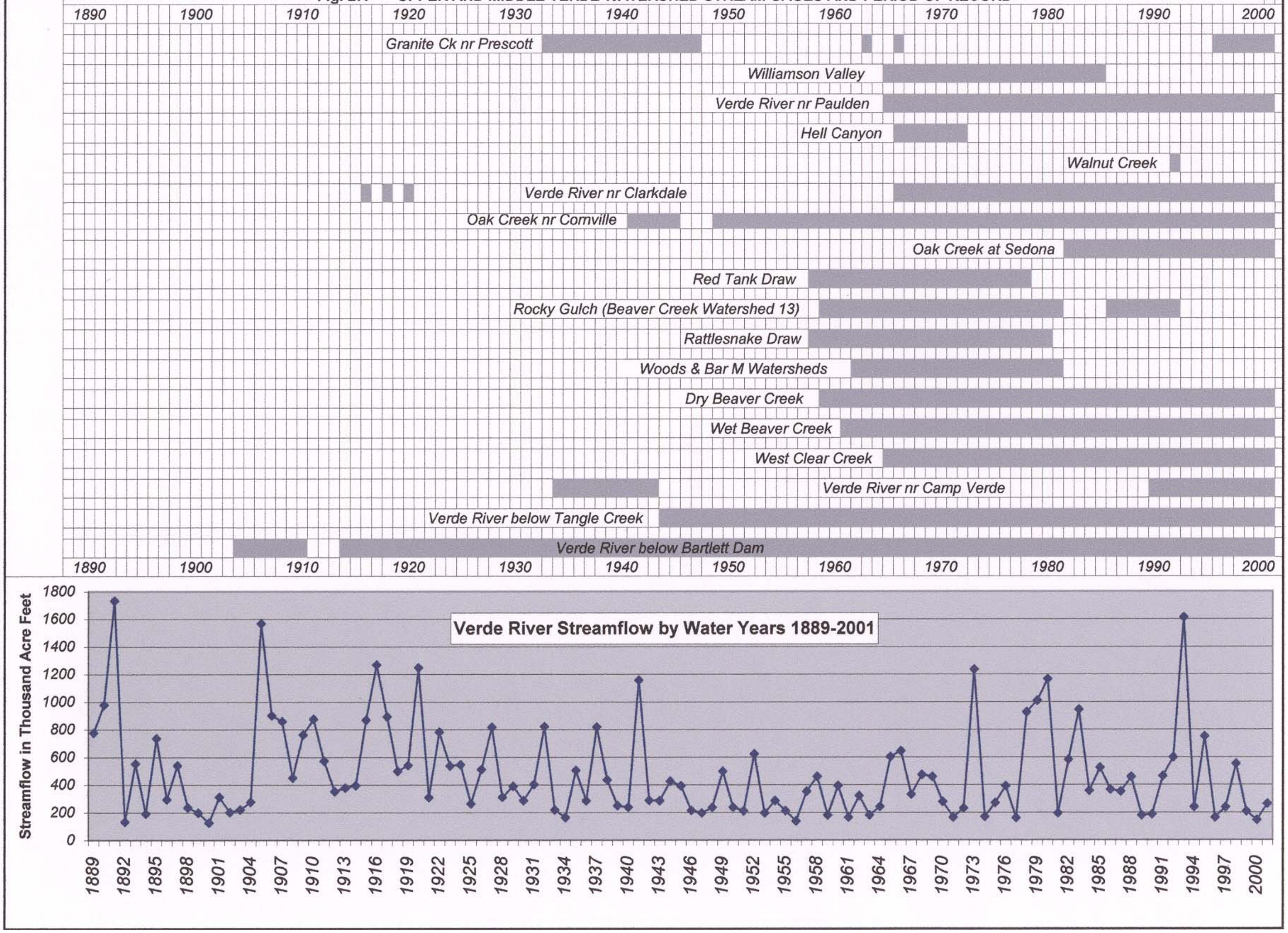


Fig. 26. UPPER and MIDDLE VERDE WATERSHED
Stream Gages and Watershed Boundaries
Stream Gage
Watershed Boundary
Prescott AMA Boundary
Beaver Creek Watershed
Stream Gage
Hell Canyon
Walnut Ck
Verde nr Paulden
Williamson Valley
Verde nr Clarkdale
Prescott AMA
Granite Ck
Oak Ck at Sedona
Bar M
Woods Cn
Rattlesnake
Rocky Gulch
Oak Ck nr Cornville
Dry Beaver
Red Tank Dr
Wet Beaver
West Clear Ck
Verde nr Camp Verde
Printed from TOPO! ©2001 National Geographic Holdings (www.topo.com)

Fig. 27. UPPER AND MIDDLE VERDE WATERSHED STREAM GAGES AND PERIOD OF RECORD



4) - Water Rights and Uses – The Arizona Department of Water Resources maintains records on water uses and rights. Data bases are available via CD-ROM for both surface water uses and wells.

5) - Floodplain Areas – The Federal Emergency Management Agency (FEMA) is responsible for floodplain delineation. Floodplain maps have been prepared and are available covering all areas within the watershed. Map scale varies, depending on drainage patterns and presence of developed or potentially developable areas subject to flood damage. Indexes of coverage are on file at Yavapai County Flood Control office, Prescott and Coconino County Community Development Department in Flagstaff.

C. Biological Communities

1) Vegetation – Vegetation maps covering the watershed are part of statewide maps displayed in ALRIS. The map selected for use in this report was digitized from a base map prepared by Brown and Lowe at a scale of 1:100,000. In the ALRIS index it is labeled “Natveg”. Another commonly used vegetation map from ALRIS is GAP (labeled “Gapveg”). It has been developed from satellite imagery and is at a scale of 1:100,000. It has much greater resolution -- i.e., it classified vegetative communities in more detail – however, it has not been fully ground checked.

The TES surveys for the National Forests contain detailed vegetation information, in addition to soil classification and mapping, at a scale of 1:24,000.

Riparian vegetation is included in an ALRIS coverage prepared by the Arizona Game & Fish Department, mapped at a scale of 1:100,000. Riparian inventories are available through the National Wetlands Inventory of the U.S. Fish and Wildlife Service with descriptions, metadata, availability, etc. accessed at http://www.nwi.fws.gov/. The inventories are displayed on 7.5 minute (1:24:000) USGS maps. More detailed riparian inventories have been conducted by the BLM and Forest Service.

D. Cultural Features

1) Landownership – In addition to coverage on ALRIS and CRBS, for the majority of the watershed which is in Yavapai County, detailed information on landownership, including individual parcel ownerships, can be obtained via the internet at: http://www.co.yavapai.az.us/services/MappingIndex.asp. Coconino County has GIS coverage for a number of layers, including assessor maps and parcels available for purchase at: http://co.coconino.az.us/gis/maprequest.asp .

2) Transportation systems - Both Coconino and Yavapai County include roads and highways in their GIS coverages.

E. Miscellaneous Coverages

1) Population – Information from the census, with population and other demographics by census designated places is available at http://www.census.gov/census2000/states/az.html then “State by Place”.

Population projections within Arizona are made by the Department of Economic Security and. Projections made in 1997 for specific communities within the watershed are at: http://www.de.state.az.us/links/economic/webpage/popweb/subco97.html

2) Historical – Repositories of historical records, maps and photographs within and adjacent to the watershed include both the Sharlot Hall Museum in Prescott and the Special Collections at the Northern Arizona University Library. Information and catalogs of archived materials is available at: http://www.sharlot.org/archives/ and at http://www.nau.edu/library/speccoll/. There are links to other sources of historical information, e.g., the Hayden Arizona Historical collections at Arizona State University.

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APPENDIX. SAMPLE SUBWATERSHEDS

The sample subwatersheds are described on page 29 and their location illustrated in Figure 3.

Analysis using the Runoff Curve Number (ROCN or CN) procedure was deemed appropriate for relative comparisons where the function of the soil-atmosphere interface was in question, i.e., the effect of the soil, vegetation, and land use in combination on infiltration and surface runoff. The procedure is widely used and popular with practitioners. References are varied but the most common is the Natural Resources Conservation Service (NRCS) Engineering Handbook, Hydrology section. Specific relationships between land use and or vegetation types and densities are also found in several references, e.g., Zeller, 1981, etc.

The use of a water yield prediction for the ponderosa pine subwatersheds was considered, i.e., the Baker-Kovner regression equation. However, the primary input of density in forest basal area was not readily available from agency records. The amount of time necessary to inventory it on the sample subwatershed was determined to not be warranted by the model predictions it might achieve. Instead a descriptive and qualitative approach was used.

Analysis of the sample subwatersheds was done using available data sources. The Forest Service Terrestrial Ecosystem Surveys and maps at 1:24,000 scale were used to obtain acreages, using 64 dot/inch^2 dot grid. For the portion covered by NRCS surveys on the Sheepshead Watershed, mapping unit lines were transferred from Orthophoto mosaic to the TES base map. Elevations and distances were obtained from USGS 1:24,000 series maps using software by TOPO! From National Geographic Maps.

Among the effects of land uses are roads and impoundments. The following table illustrates these factors for the subwatersheds which are not urbanized.

Name	Size in Mi^2	Road Density Miles/Mile^2	Percent Area Above Impoundments	Comments
Witty Tom	6	1.2	79* (15)	Also 2.8 miles of railroad. Railroad embankment creates primary impoundment.
Sawmill	4.8	1.4	26	One impoundment
Sheepshead	6	1.6	30	1 mile of paved highway, being converted to four lane, divided.
Watershed 8	3	3.3	56	One impoundment
Cougar Park	7.7	2.0	30	4 miles paved highway
TOTAL	27.5	1.8	42** (29)	

* Without the one major railroad embankment impoundment, would be 15 percent of area.
** Without the one major railroad embankment impoundment in Witty Tom, would be 29 percent of area

The following is more detailed information on each of the subwatersheds.

Witty Tom Subwatershed

General description. The Witty Tom sample subwatershed is located in the upper Verde and straddles the boundary between Yavapai and Coconino Counties. It drains directly into the Verde River about three miles upstream from the Perkinsville Bridge. Comprising about 3820 acres, or about 6 square miles, it is long and narrow, sloping to the south toward its confluence with the Verde. The primary drainageway is approximately eight miles in length from the Verde River confluence to the top of the watershed. Terrain is generally rolling with a couple of rounded erosional remnant hills in the southwest and an incised drainage in the lower 1.5 miles. Elevation ranges from about 3900' at the Verde River to 5450' at the upper end of the watershed.

Surface geology is dominated by Quaternary volcanics, predominantly basalt, over the majority of the uplands. These are underlain by Paleozoic sedimentary formations, which are exposed in portions of the drainages and the southern, lower elevation, portion of the subwatershed. Outcrops of Coconino sandstone are present in the northern portion and contain several quarries -- both active and inactive.

Soils are predominantly Haplustalfs and Calcic Ustochrepts. TES mapping identifed 15 different mapping units being present in the watershed. Vegetation is predominantly pinyon-juniper; however a significant amount is in an earlier successional stage, having been treated to remove pinyon and juniper trees in the 1950's and 60's.

Land use. Aside from the site specific quarries mentioned above, the general land use has been grazing of domestic livestock since the late 1800's. A limited amount of dispersed recreation, primarily big game (deer and elk) hunting, occurs in the general area. The railroad traverses the area generally paralleling the Verde River for about 2.75 miles within the watershed. Several roads are present. Approximately 1.2 miles of the road between Jerome and Williams crosses the watershed and there are an additional approximately 6 miles of native-surfaced, low maintenance standard roads within the watershed.

There is evidence of historic wood cutting of pinyon and juniper in the more accessible portions of the watershed. During the early 1900's woodcutting was widespread to supply the mining communities associated with the Jerome mines.

The history of livestock grazing is like much of the Verde watershed. It is located within the Witty Tom pasture of the Sand Flat Allotment on the Prescott National Forest. A history of grazing use since about 1911 is included in the 1979 Sand Flat Range Analysis and has been updated to present (Ryan 2001). Once part of a much larger grazing allotment, the overall area has been divided into smaller units, with adjustments to grazing allotment boundaries over the years, and some splitting into smaller pastures as could be accommodated by availability of developed water. The number of cattle grazed on the area declined through the 1920's, 30's, 40's and into the '50s. The grazing permittees commonly took non-use on a substantial portion of the grazing permit due to lack of available forage, especially during the drought of the mid-century. Since 1986 the allotment has been used for a six month winter-spring period (November through May).

There are five earthen stock tanks within the watershed, two formed by embankments created for the railroad. Only about 20 percent of the watershed flows directly to the Verde River, without being above an impoundment (stock tank) within the watershed. The following table illustrates stock tanks and drainage areas.

Tank	Drainage area acres		Construction date*	Comments
Vineyard	80		1967	
Mexican	50		ca 1956	
Witty Tom	370		ca 1918	
Boggy	2920**		1960	Impoundment by railroad grade. Outlet via CMP approx. 8 ft. diameter. Large amount of sediment buildup.
Trestle	90		1960	Impoundment by railroad grade. Outlet via perforated standpipe. Considerable sediment buildup.
*From Forest Service records and Stock Pond Registration Act applications.				
**Includes drainage areas of Vineyard, Mexican, and Witty Tom Tanks.				

<u>Current Conditions</u>. Initially the area was compared to TES evaluations. Soil condition by TES unit was classified in the TES report and refined in a later watershed evaluation. Table A-1 displays the soil condition ratings from the TES along with the calculated soil loss rates from the Universal Soil Loss Equation (USLE). Four mapping units comprising 25% of the watershed were classified as satisfactory, six units comprising 47% were classified as impaired, and the remaining five units, or 28% of the area, were classified as unsatisfactory. As the table displays, there is little correlation between USLE soil loss calculations and the assigned condition rating. Three of the four TES units classified as satisfactory are calculated as having current soil loss greater than the tolerance level (and these same three display a “natural”, or best condition, as still exceeding the tolerance level of soil loss.) By contrast none of the TES units classified as impaired or unsatisfactory had calculated current soil loss rates in excess of the tolerance level. Thus, soil condition classification was based on factors not well described in the TES report. This helps to confirm limitations described by Forest Service soil scientists for use of the USLE procedure in rating soil condition.

A review was made of TES field notes for several of the units classified as impaired and unsatisfactory. Notes were based on field sample points and transects. Examples of field notes specifically addressing soil condition that were used in classifying as impaired or unsatisfactory included:

> “lost __ inches [or centimeters] of A horizon” [*varying from 2 cm to 10 cm*]
> “plant pedestalling common (1-3 cm)”, “up to 1 inch around grasses & forbs, 3 inches around trees and shrubs”
> “cryptograms holding some soil in place – pedestalling around cryptograms”
> “platy structure in surface of A horizon”
> “about ½ cm vesicular crust on surface”
> “vesicular pores in A1 & A2 [horizons] have low vertical continuity”

“surface compaction”, (numerous reports of compaction of surface layer varying from 2 to 10 cm)
“cracks in surface 4-6 inches deep and ¾ inch wide. Area is starting to lean toward vertic”
“obvious sheet and rill erosion, a few gullies across landscape”
“debris dams common, few rills forming and desert erosional pavement present”
toward vertic”
“obvious sheet and rill erosion, a few gullies across landscape”
“debris dams common, few rills forming and desert erosional pavement present”
“pipes and cracks present”
“litter removed by water erosion”
“litter not evenly distributed, lack of perennials [vegetation]”

Table A-1. WITTY TOM SUBWATERSHED SOIL CONDITION RATINGS

TES#	Acres	Condition rating	USLE SOIL LOSS CALCULATIONS tons/ha/yr[5] [6]			
			Potential	Natural	Current	Tolerance
430	47	Satisfactory	28.5	9.1, 11.3	11.3, 14.4	6.7, 4.5
441	679	Satisfactory	11.1, 15.3	3.6, 4.1	4.4, 5.0	4.5, 6.7
465	20	Satisfactory	19, 20.7	7.7, 8.2	9.4, 9.7	2.2, 4.5
466	224	Satisfactory	23.4, 19.9	8.1, 5.6	9.7, 6.6	4.5
440	788	Impaired	1.7, 2.2	0.4, 0.7	0.5, 0.9	6.7, 4.5
459	72	Impaired	9.6, 10.1	2.1, 3.3	2.5, 3.4	6.7, 4.5
464	187	Impaired	9.7, 11.6	2.6, 3.2	3.3, 3.8	6.7, 4.5
471	376	Impaired	3.5, 2.9	1.7, 1.2	2.5, 1.8	6.7
473	280	Impaired	2.0, 2.3	0.5, 0.6	0.9, 1.2	6.7
474	85	Impaired	12.4, 17.6	3.9, 2.1	4.1, 2.6	4.5
439	11	Unsatisfactory	2.0	1.1	1.3	2.2
456	392	Unsatisfactory	3.1	0.9	1.0, 1.2	6.7
458	37	Unsatisfactory	6.0, 6.2	1.2, 1.5	1.9, 2.5	6.7
463	386	Unsatisfactory	1.1, 1.8	0.4, 0.7	0.5, 0.9	6.7, 2.2
472	238	Unsatisfactory	3.0, 2.0	1.3, 0.5	2.2, 0.9	2.2, 6.7

Field review was generally consistent with these observations.

[5] USLE calculations for soil loss rate:
potential– with no protective cover. This is the maximum rate.
natural – with cover that would occur under conditions associated with a climax class
current – with current cover
tolerance – allowable soil loss while sustaining inherent soil productivity

[6] Most TES units have two or more components identified. The TES report describes and gives USLE calculations for the two largest in acreage. Where two numbers are given under the categories of potential, natural, current, or tolerance they represent the two components of that TES mapping unit with the first being from the component having the largest acreage.

The TES report gives ground cover components for current (at the time of field mapping – mid 1990's) and "natural" conditions. Field review and analysis of range transects suggested a considerable amount of variation from point to point and time to time, but generally agreed with the cover conditions displayed in the TES report. One significant exception was found. TES unit 471, which is an area which has been treated to remove pinyon and juniper, appeared to have enough difference from the unit average in the TES report that an adjustment was made. A 500 point pace transect within the unit in the watershed found significantly higher cover density and lower bare soil than the TES average. Because of known variation within the unit, this was averaged with the TES report and that midpoint between the two used to represent current conditions.

Range condition and trend transect clusters (Parker 3-Step) are read periodically to evaluate changes over time. For each cluster three 100 foot transects are marked with angle iron placed in the ground at each end so that a tape can be stretched and repeat measurements taken at one foot intervals. They are commonly placed in locations expected to respond to livestock impacts, i.e., in areas of livestock use. Therefore they may not be representative of a watershed area as a whole. Four were found within or immediately adjacent to the Witty Tom subwatershed and are illustrated in Figures A-1 and A-2. Figure A-2 illustrates the protective ground cover comparable to that used for determining runoff curve numbers for comparative analysis. One transect cluster was established in 1955 and the other three in 1965. Two of them were read in 1975 and all four in 1997. The last reading in 1997 had essentially the same ground cover density as 1965 on two transects and below on the remaining two. Three of them are in areas where pinyon-juniper stands had been treated to remove them or greatly reduce the density. Transect C6, which has the lowest cover density, is in a fairly dense stand of pinyon-juniper. Between 1965 and 1997 it had no net change in vegetation and litter cover but increased in total protective ground cover. This was because the amount of bare soil was reduced at the expense of rock fragments, indicating that fine materials had been removed, leaving rock fragments, and tending toward development of an erosion pavement.

As can be seen there is considerable variation over time in ground cover density. Some of this is due to fluctuations in weather, some due to reading at different seasons of the year, some due to livestock management and impacts and very likely some may be due to varying protocol in reading the transects, e.g., classification of annual herbaceous plants as litter or as bare soil (Mundell, 2002).

Table A-2 displays the current and natural cover conditions for the TES units within the subwatershed. An analysis was made of storm runoff for current and natural conditions using standard precipitation frequencies of 2,5,10,25,50, and 100 years from NOAA atlas and displayed in the Arizona Department of Transportation Highway Drainage Design Manual Hydrology. Table A-2 and Figure 9 (page 46) display the differences. As is shown, the differences in calculated peak flow range from 7.5 to 10.6 percent, the greater percentage difference being in the most common storms – 2 year. Plotting the frequencies shows that a peak flow that would occur on an average ten year frequency

Fig. A-1. Vegetative Cover (plant + litter) 1955-1997, Witty Tom Watershed, Range Condition Transects

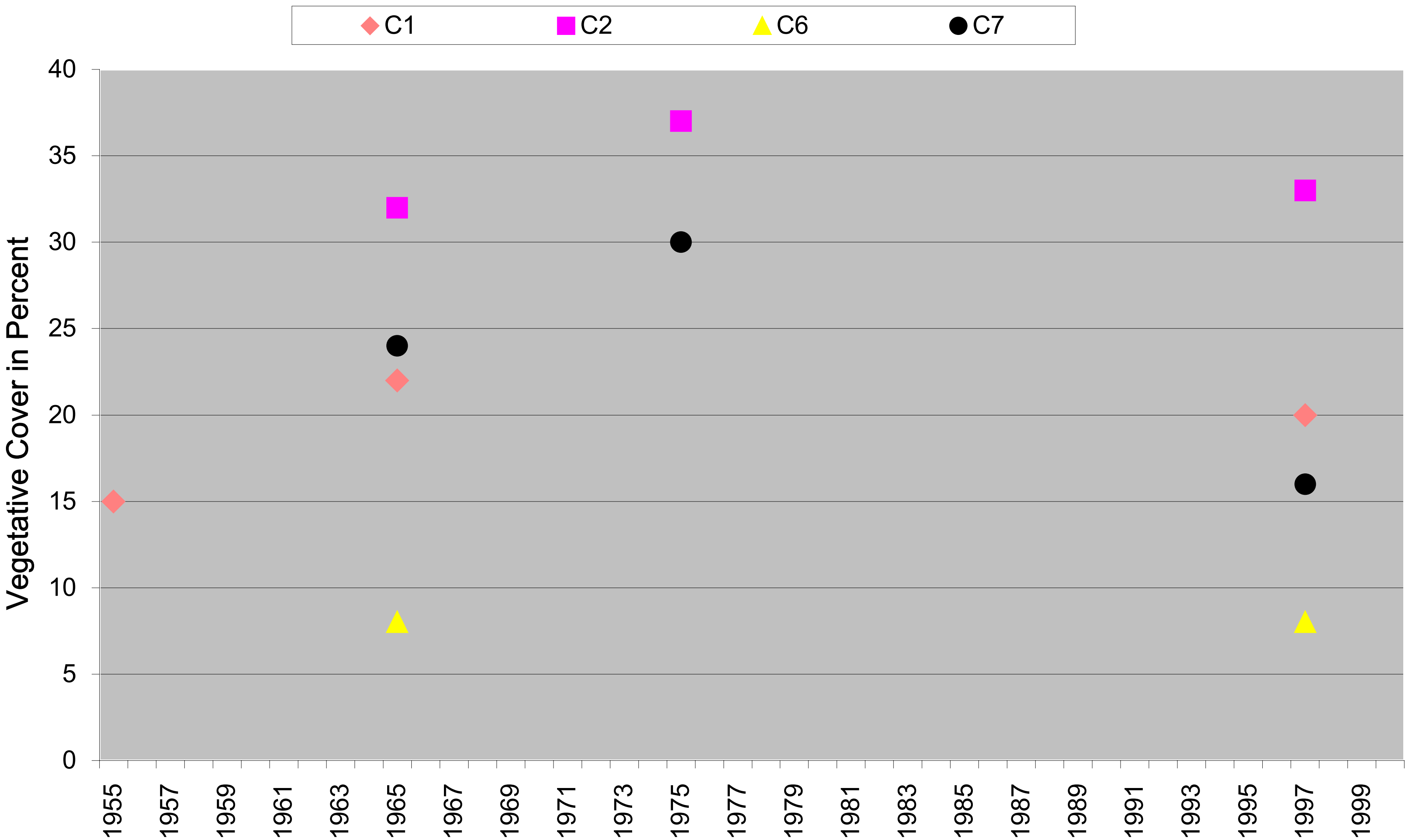

Fig. A-2. Protective Ground Cover (plant + litter + allowable rock cover), Witty Tom Subwatershed, Range Condition Transects

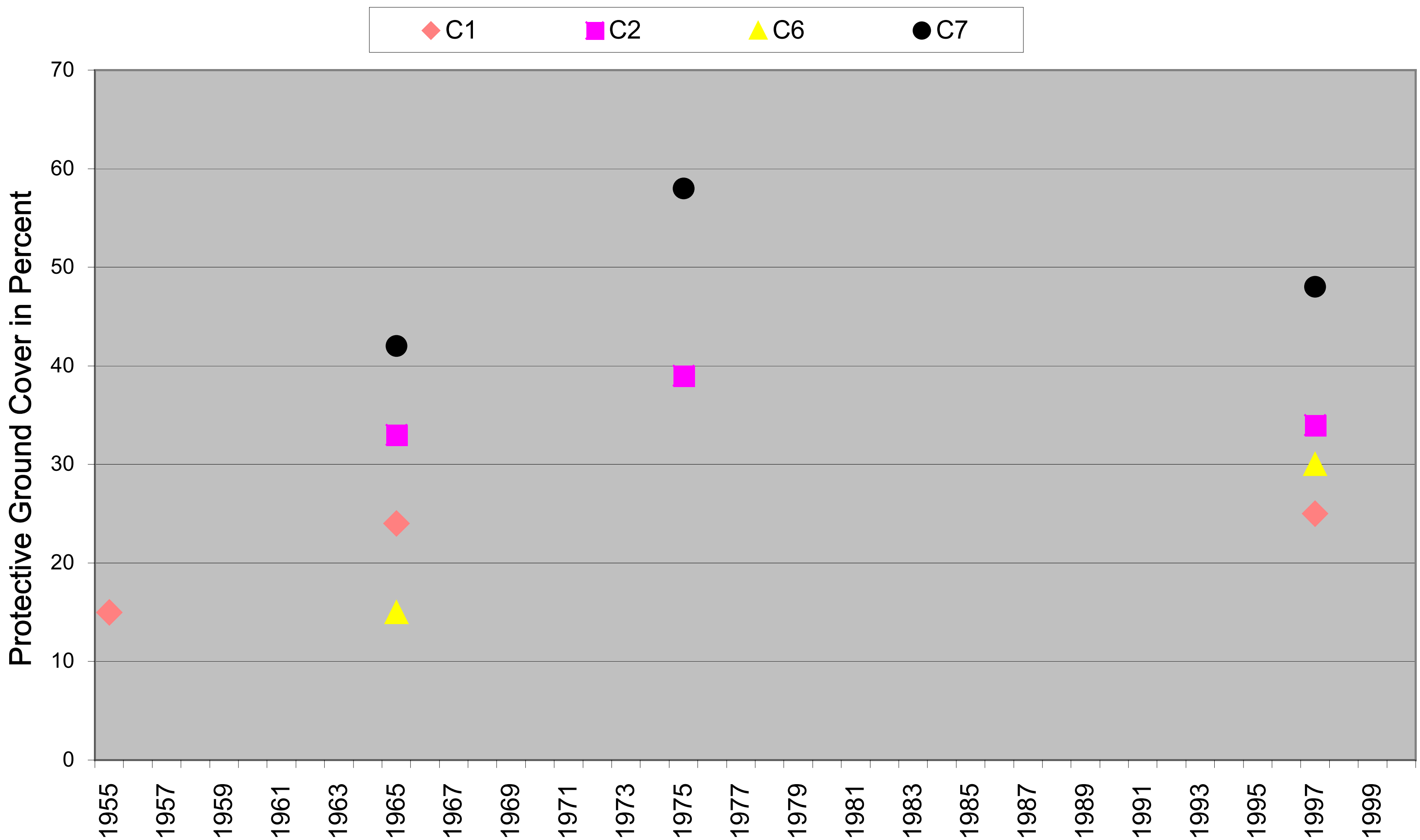

Table A-2. WITTY TOM SUBWATERSHED CURRENT AND NATURAL CONDITIONS													
TES#	Acres	Condition rating	Soil Hyd group	Current Condition		Natural Condition		Storm runoff from 10-yr 6 hr storm, 2.6 in.					
				Cover %	ROCN	Cover %	ROCN	Current		Natural		Difference	
								inches	acre-ft	inches	acre-ft	inches	acre-ft
430	47	Satisfactory	D	60	86.1	65	85.4	1.009	3.95	0.968	3.79	0.041	0.16
439	11	Unsatisfactory	D	42	88.5	57	86.5	1.162	1.07	1.033	0.95	0.129	0.12
440	788	Impaired	D	67	85.1	73	84.4	0.950	62.38	0.917	60.22	0.033	2.17
441	679	Satisfactory	D	64	85.6	69	84.9	0.979	55.40	0.939	53.13	0.040	2.26
456	392	Unsatisfactory	B	52	57.4	60	53.2	0.063	2.06	0.021	0.69	0.042	1.37
458	37	Unsatisfactory	C	55	71.3	70	66.2	0.359	1.11	0.221	0.68	0.138	0.43
459.1	50	Impaired	C	60	69.6	65	67.9	0.309	1.29	0.263	1.10	0.046	0.19
459.2	22	Impaired	D	54	86.9	59	86.2	1.058	1.94	1.015	1.86	0.043	0.08
463	386	Unsatisfactory	D	57	86.5	71	84.6	1.033	33.23	0.922	29.66	0.111	3.57
464	187	Impaired	D	64	85.6	69	84.9	0.979	15.26	0.939	14.63	0.040	0.62
465	20	Satisfactory	D	43	88.3	45	88.1	1.149	1.92	1.135	1.89	0.014	0.02
466	224	Satisfactory	D	56	86.7	56	86.7	1.046	19.53	1.046	19.53	0.000	0.00
471	376	Impaired	C	44	75.1	55	71.3	0.487	15.26	0.359	11.25	0.128	4.01
472	238	Unsatisfactory	D	30	90.1	50	87.5	1.274	25.27	1.096	21.74	0.178	3.53
473	280	Impaired	B	53	56.9	72	47	0.057	1.33	0.000	0.00	0.057	1.33
474	85	Impaired	D	60	86.1	65	85.5	1.009	7.15	0.974	6.90	0.035	0.25
Total	3822								248.12		228.00		20.11

under natural conditions would occur on an average eight year frequency under current conditions, a natural condition peak flow of 25 year frequency would occur at about 20 year frequency under current conditions, etc. The result would be slightly greater impact on channels and slightly less time periods for recovery between disturbances.

Channel Condition - Visual observations and field notes were made of channel conditions. In the main channels upstream from the quarries the channels appeared to be stable and handling flows and sediment adequately with a variety of sediment sizes present representative of the source materials. Downstream from the quarries and associated roads a reach was examined above the Clarkdale-Williams road. This reach showed evidence of active lateral bank cutting and undercutting on meanders.

Boggy Tank has accumulated a large amount of sediment, derived from both bed load and suspended material. As this impounds flows from over 2900 acres, or more than 75 percent of the watershed, there is a noticeable effect on sediment downstream. The segment downstream toward the Verde appeared to have less sand and gravel size material than upstream from the tank. At the confluence with the Verde River the channel is sharply incised and is above the river level. This is in strong contrast to the next tributary downstream, Government Canyon where sand and gravel deposits create an area of aggradation at the mouth. Government Canyon has only a very small percent of its area above impoundments. However, it does have more of its area in exposed sandstones and more quarries (Carr, 1999).

Opportunities for Watershed Improvement - There are opportunities for watershed improvement on several of the TES units. Vegetation management to improve soil ground cover and surface horizon conditions which affect infiltration. TES units 463, 471, and 472 have the greatest difference between current and natural conditions as calculated through the CN method, based on ground cover. The analysis suggests some potential benefits on the other TES units except 466. Detailed field analysis and treatment on a limited basis, followed by evaluation and appropriate adaptation, is suggested.

Sawmill Subwatershed

General description. The Sawmill sample subwatershed is located in the Santa Maria Mountains within the Prescott National Forest, within Yavapai County. It drains into Williamson Valley, tributary to Big Chino Wash . Comprising about 3060 acres, or about 4.8 square miles, it is generally oval in shape, draining to the east. Sawmill Wash continues downstream for about 3 miles to a confluence with Pine Creek to form Williamson Valley Wash.

The primary drainageway is approximately 4.1 miles in length from the top of the watershed to the lower end. Terrain is generally hilly with slopes of 20 percent or greater being common. Elevation ranges from about 4950 at the lower end to 6150' on Sawmill Mountain in the southwest corner.

Surface geology is predominantly granitic with some metamorphics, primarily schist. The TES survey classifies about 15 percent of the watershed as having alluvial soil parent material and about 5 percent as basalt.

Soils are generally coarse textured, e.g., sandy loams and coarse sandy loams, with high rock content, and frequently shallow. Nine TES mapping units were present in the watershed. Three of these were divided into two components described in the TES report but not delineated at the scale of mapping. This was due to differences in hydrologic soil group and/or current and natural cover conditions for the components that was relevant to hydrologic analysis. Although the Prescott National Forest TES report did not give hydrologic interpretations, tentative classification to soil hydrologic group for the purposes of analysis was done using comparison with the previous NRCS/Forest Service soil survey for western Yavapai County which included this area (that survey did include classification of soil hydrologic group), along with comparison of soil depths and textures of classified soils with the soils in this watershed. This resulted in about half of the area being rated as soil hydrologic group C and the other half as group D.

Vegetation is predominantly chaparral, intergrading with ponderosa pine at the highest elevations and pinyon-juniper at the lower elevations. Turbinella and Emory oak, manzanita, mountain mahogany, silktassel and squawbush are common shrubs, along with pinyon pine, alligator and Utah juniper trees. There are several understory herbaceous species with blue and sideoats grama, three-awn, and wolftail being among the more common. However, the herbaceous species are quite sparse in ground cover due to competition with shrubs and trees. Recurrent, episodic fire has maintained the plant community in a portion of the watershed.

Land use. Livestock grazing is the longest term use in the area. There is some dispersed recreational use, primarily hunting for mule deer and javelina in season as regulated by the Arizona Game and Fish Department.

The Camp Wood road, Forest Road 21, passes lengthwise through the southern portion of the watershed. This road is periodically graded and maintained and is approximately 3.0

miles within the watershed. In addition there are about 3.8 miles of low standard native surface road (identified as four-wheel drive road on some maps).

There is one stock tank, Sawmill Tank, located in the west-central part of the watershed. The area upstream from the tank comprises approximately 26 percent of the watershed. Field review indicated that the natural bedload movement of sand and gravel down the channel reduces its storage capacity and it must be periodically "cleaned", i.e., accumulated sediment pushed out of the reservoir area to areas above the spillway level, using a bulldozer.

Current Conditions. The Prescott National Forest TES evaluations classified 69 percent of the watershed as being in "Satisfactory" condition, 30 percent as "Impaired", and 1 percent as "Unsatisfactory". None of the impaired or unsatisfactory classifications were based on calculated sheet and rill erosion rates as compared to tolerance levels. Instead, they were based on a number of factors as described with the discussion for the Witty Tom watershed.

Field review for the unit classified as unsatisfactory comfirmed this rating. This is a pinyon-juniper site on alluvial soils with evidence of disturbance from livestock grazing and motor vehicles, having widespread sheet and rill erosion.

Table A-3 displays condition ratings, plus current and natural cover conditions and runoff curve numbers (ROCN) by TES mapping unit. In addition it compares the runoff from a 10 year 6 hour storm between current and natural conditions. The calculated storm runoff from a 10-year 6-hour storm of 2.6 inches is 13 percent higher for current conditions than for natural conditions.

Field review of channels found conditions generally reflective of surrounding watershed conditions. In the upper portions of the watershed dominated by TES units rated as satisfactory condition channels reflected considerable movement of sediment from the coarse grained granitic soils. However, they appeared to be generally stable, i.e., no general degradation or aggradation. However, in the lower section where the channel passed through predominantly impaired areas there were segments of active channel bank erosion.

Opportunities for Watershed Improvement - By definition, it would be expected that areas which are "unsatisfactory" or "impaired" can be improved. The relatively small area classified as unsatisfactory is on alluvial soils and the TES report indicates a significant opportunity for improvement of cover density. However, its location next to the Camp Wood road and the evidence of vehicular traffic across the area, suggest that it will be a challenge to protect investments in improvement from further damage.

Table A-3. SAWMILL DRAW SAMPLE SUBWATERSHED CURRENT AND NATURAL CONDITIONS															
TES#	Acres	TES Condition Rating	Hyd Soil Group	Current Conditions		Natural Conditions		ROCN Difference	Storm runoff from 10-yr 6 hr storm, 2.6 in.					
				Cover %	ROCN	Cover %	ROCN		Current		Natural		Difference	
									inches	acre-ft	inches	acre-ft	inches	acre-ft
425.1	158	Impaired	D	67	77.9	72	76.7	1.2	0.848	11.17	0.789	10.39	0.059	0.78
425.2	105	Impaired	C	61	65.6	71	61.9	3.7	0.354	3.10	0.249	2.18	0.105	0.92
430	154	Satisfactory	D	58	80.1	63	78.6	1.5	0.964	12.37	0.884	11.34	0.08	1.03
434.1	384	Impaired	C	60	67.8	70	64.2	3.6	0.426	13.63	0.312	9.98	0.114	3.65
434.3	35	Unsatisfactory	C	52	72.4	67	67.2	5.2	0.598	1.74	0.405	1.18	0.193	0.56
461	13	Impaired	D	72	84.5	77	83.8	0.7	1.226	1.33	1.181	1.28	0.045	0.05
462	251	Impaired	D	64	78.4	69	77.4	1	0.874	18.28	0.823	17.21	0.051	1.07
468	50	Satisfactory	D	58	80.1	63	78.6	1.5	0.964	4.02	0.884	3.68	0.08	0.33
477.1	970	Satisfactory	C	70	62.3	80	60	2.3	0.26	21.02	0.209	16.89	0.051	4.12
477.2	794	Satisfactory	D	55	81.2	60	79.5	1.7	1.026	67.89	0.932	61.67	0.094	6.22
479	103	Satisfactory	D	67	77.9	72	76.7	1.2	0.848	7.28	0.789	6.77	0.059	0.51
505	43	Satisfactory	D	67	77.9	69	77.4	0.5	0.848	3.04	0.823	2.95	0.025	0.09
Total	3060									164.86		145.54		19.32

Runoff Curve Numbers from Mountain Brush vegetative type relationships with exception of 434.3 and 461 which are from Juniper-Grass and 434.1 which is an average of Mountain Brush and Juniper-Grass.

Sheepshead Subwatershed

General description. The Sheepshead sample subwatershed is located in the Verde Valley in Yavapai County. It drains directly into Oak Creek in the unincorporated community of Cornville approximately 10 (very circuitous and serpentine) river miles upstream from its confluence with the Verde River. Comprising about 3850 acres, or about 6 square miles, it is long and narrow, sloping to the south-southeast toward its confluence with Oak Creek. The central portion is narrower than both ends, giving somewhat of an hourglass shape. The primary drainageway is approximately 6.8 miles in length from the Oak Creek confluence to the top of the watershed. Terrain is mostly gently sloping with a small portion in the northwest corner being the steep side slopes of a mesa and the lower one mile of Sheepshead Draw being in a sharply incised drainage. Elevation ranges from about 3280' at Oak Creek to 5450' at the upper end of the watershed.

Surface geology is from the Verde Formation of Tertiary age formed of lacustrian, or lakebed, deposits. Limestone, siltstone and marl are found in this formation, with some tongues of interbedded basalt flows and gravel deposits. Most of the surface appears to be fine grained and carbonate.

Soil mapping has been done by both the Natural Resources Conservation Service (NRCS) and the Forest Service. The NRCS conducted a survey to the series level for the majority of the watershed which is Arizona State Trust land, plus a small portion which is private. The Forest Service surveyed at the family level for the remainder which is National Forest. There is some overlap of the two surveys.

Soils are strongly affected by the calcium component of the parent geology. Forest Service TES mapping identified 5 mapping units in the National Forest portion of the watershed. NRCS mapping identified four mapping units in the State Trust portion. There is obviously some overlap; however the surveys are not coordinated. For purposes of watershed analysis the mapping and soil interpretations (e.g., hydrologic soil group) from NRCS were used for Arizona State Trust Land and Forest Service TES mapping and interpretations for National Forest land.

Vegetation is predominantly desert shrub-grassland, with varying amounts of shrubs and small trees including mesquite, catclaw acacia, creosotebush, crucifixion-thorn. A variety of grasses and forbs are present including black grama, tobosa, threeawn, needle-and-thread grass, and sand dropseed. On steeper, east-facing slopes Utah juniper and turbinella oak are present. In the lower section of channel there are several springs supporting a riparian community, including cottonwood, willow, baccharis, and cattail.

Land use. The watershed is divided between Arizona State Trust land -- about 2155 acres or 56 percent -- and Coconino National Forest for the remaining 1695 acres or 44 percent. The general land use has been grazing of domestic livestock since the late 1800's. The Arizona State Trust Land must be managed for revenue production under the Arizona constitution. Grazing leases are issued for this use. The National Forest portion was predominantly on the Spring Creek grazing allotment for many years but has now been amalgamated into the very large Windmill Allotment. Livestock grazing is seasonal during the cooler season fall-winter-spring months.

The proximity to nearby residential areas -- Cornville, Cottonwood, Sedona -- results in an increasing amount of dispersed recreation and vehicular use. Approximately one mile of Highway 89A between Sedona and Cottonwood crosses the watershed. In the spring of 2002 it is in the process of being upgraded to a four-lane divided highway. The Bill Gray Road provides access to a residential development on an inholding within the Coconino National Forest. Two miles of this graded and maintained road pass north-south through the northern (headwater) portion of the watershed. There are an additional approximately 6.5 miles of native-surfaced, low maintenance standard roads within the watershed.

There is one major earthen stock tank, Sheepshead Tank, along with an adjacent sand trap which traps coarse sediment moving down the channel and impounds some water. The Stockpond Registration filed by the Forest Service lists a construction date of 1941 and capacities of 5.7 and 1.9 acre-feet, respectively, based on 1978 measurements. The area above the stock tank and sand trap comprises about 30 percent of the watershed.

Current Conditions. The National Forest portion of the watershed was compared to TES evaluations. One TES unit was classified as "Unsuited", or essentially "Inherently Unstable", as the calculated natural sheet and rill erosion rate was higher than the calculated tolerance, or allowable, rate. This was primarily due to its steep slope, averaging 35-40 percent. The other units were classified as satisfactory. Field review suggested that several would not have rated satisfactory if subjected to the rating system later developed and used on the Prescott National Forest. The presence of sheet and rill erosion, plant pedestalling, and localized sediment deposits was noted in field reviews. In addition, there is a very active gully system in portions of the watershed. The Forest Service conducted an erosion inventory in the late 1970's. This inventory recorded approximately 8.5 miles of active gullies between two TES units. One in the upper watershed had more than 5 miles per square mile, while one in the lower portion had about 4 miles per square mile. Field review suggested the density in some of the lower portion is considerably greater. Although there is not a similar inventory on State Trust lands, field review noted the presence of a number of active gullies on these, as well. In particular the southwestern part of the watershed has a high density of deep, active gullies, often as little as six feet wide but six or more feet deep. Bank slumping and subsequent erosion is common. The incision of the base level downstream is resulting in multiple, often parallel, channels incising and working their way headward toward the watershed boundary.

Table A-4 illustrates the acres by TES unit on National Forest land and soil mapping unit on state trust and private land. It also includes current and natural cover and runoff curve numbers. (TES descriptions of cover density were supplemented by cover transects on the large area mapping units on both National Forest and state trust land. Natural cover density was taken from TES, with correlations to the nearest classification for state trust land.)

Table A-4. Sheepshead Watershed Current and Natural Condition Comparison

TES/ Soil Unit	Acres	Hyd Gp	Current Cov	Current **CN**	Potential Cov	Potential **CN**	CN diff	**10 yr-6 hr storm runoff in inches** Current in	Current ac-ft	Natural in	Natural ac-ft	Difference in	Difference ac-ft
National Forest													
350.1	189	D	50	**87.5**	65	**85.4**	2.1	1.072	16.88	0.945	14.88	0.127	2.00
350.2	102	B	47	**74.1**	62	**52.1**	22	0.436	3.71	0.012	0.10	0.424	3.60
381	910	B	15	**76.2**	35	**66**	10.2	0.512	38.83	0.206	15.62	0.306	23.21
385.1	40	D	45	**88.1**	55	**86.8**	1.3	1.110	3.70	1.028	3.43	0.082	0.27
385.2	50	B	45	**61**	55	**55.9**	5.1	0.110	0.46	0.041	0.17	0.069	0.29
403	95	B	18	**74.7**	35	**66**	8.7	0.457	3.62	0.206	1.63	0.251	1.99
447	55	B	30	**68.5**	45	**61**	7.5	0.267	1.22	0.109	0.50	0.158	0.72
448	255	C	65	**67.9**	80	**62.7**	5.2	0.252	5.36	0.139	2.95	0.113	2.40
State Trust													
428	268	D	47	**87.8**	62	**85.8**	2	1.091	24.37	0.968	21.62	0.123	2.75
430	602	B	15	**76.2**	30	**68.5**	7.7	0.512	25.69	0.267	13.39	0.245	12.29
431	97	C	45	**74.7**	55	**71.3**	3.4	0.457	3.69	0.346	2.80	0.111	0.90
432	1188	C	12	**86.1**	35	**78.2**	7.9	0.986	97.61	0.591	58.51	0.395	39.11
Total	**3851**								225.13		135.61		89.52

Table A-5 illustrates peak flows for current and natural conditions for storms from 2-yr to 100 year and Figure 8 (page 44) in the body of the report displays this graphically. As illustrated, given peak flows occur much more frequently under current conditions than under natural conditions. For example a flow which would occur on a 10 year frequency under natural conditions occurs on an average 2.2 year frequency under conditions and a peak flow which would occur on a 50 year frequency under natural conditions occurs on an average 15 year frequency under current conditions.

Table A-5

Recurrence Interval Years	Flow in cfs Current	Flow in cfs Natural	Current Recurrence Interval of Natural Flow *	Ratio**
2	297	143		
5	518	281	<2	
10	710	412	2.2	4.55
25	992	616	7	3.57
50	1303	850	15	3.33
100	1467	976	25	4.00

* From plot of recurrence interval vs flow. For example, a flow of 412 cfs which would occur on average of 10 year recurrence under natural conditions, has a recurrence interval of about 2.2 years.

** Ratio of natural recurrence interval to current recurrence interval. Also equals ratio of a given flow under current conditions to under natural conditions, e.g., a flow of 412 cfs would occur about 4.55 times as frequently under current conditions as natural conditions.

The difference in calculated flow based on difference in ground cover and runoff curve number may be conservative, based on results found by Haynes (1993) in the adjacent Little Colorado Watershed. Haynes reported that channel incision and consequent changes in channel geometry resulted in higher peak flows, without an increase in runoff curve number.

The large amount of sediment generated from sheet, rill and gully erosion moves through the channel to the lower area where a dense riparian area traps much of the bedload. Dense cattails and baccharis slow flow and result in sediment deposition, building up a local "aquifer" of channel and bank storage downstream from the natural springs.

Sheepshead Springs have been evaluated for the effect of riparian vegetation on flow. In 1979 cattle grazing was eliminated from the area of the springs by fencing. The water rights holder for the ditch downstream from the springs expressed concern that greater riparian growth would result in losses to available water. The Coconino National Forest conducted detailed evaluations over a six year period (Johnson, 1981; Zuniga, 1985). Over this time period, riparian vegetation changed greatly, becoming much more dense and taller. However no significant change in streamflow at the ditch diversion downstream from the springs was detected. Flow at the diversion averaged approximately 0.22 cfs or about 160 acre feet per year. If it came from the surface watershed it would calculate to about 0.6 inches on an area wide basis for the watershed area upstream from it. However, groundwater divides are not synchronous with surface watershed divides, especially where the surface divides are as subtle as for Sheepshead Draw. The evaluations found gradually increasing flow downstream from the springs to the diversion. This could be due to a slightly larger watershed area contributing, or to the channel downcutting deeper into the regional aquifer. Maps in Levings (1980) suggest the potentiometric surface (water table) of the regional aquifer within the Verde formation at about the elevation at which the channel would intersect it in the vicinity of the springs. Field review suggests that continuing deposition of sediment moving down channel from upstream gully and channel erosion, and trapped by very dense riparian vegetation, may be slowly enlarging the local aquifer associated with the channel and increasing that storage.

The ditch diversion has no headgate and diverts flow yearlong, regardless of irrigation needs. This is consistent with most of the ditches in the Verde Valley. Immediately downstream from the diversion riparian vegetation is very pronouncedly less but gradually increases downstream toward Oak Creek. Field review at the confluence of Sheepshead Draw with Oak Creek did not reveal major sediment deposits in Oak Creek.

<u>Opportunities for Watershed Improvement</u> - The most dramatic watershed problem is the dense network of active gullies, especially in the southwestern part of the watershed. Analysis and design of treatment was beyond the scope of this analysis. An analysis of the situation and alternatives, including no action, is needed. Structural treatments to halt headcutting would quite expensive.

There is some opportunity for improved watershed condition in the upland areas of the watershed; however the degree of past impacts and the natural limits of the desert-shrub vegetative type will make improvement a slow process. In addition the proximity to the rapidly growing urban areas in the Verde Valley expose the area to impacts from a wide variety of vehicular activities.

Watershed 8 Subwatershed

General description. Watershed 8 derives its name from its location within the Beaver Creek Research Watersheds. It is located in the middle Verde near the watershed boundary with the Little Colorado and is in Coconino County. It drains directly to Rattlesnake Canyon, which merges with Woods Canyon to form Dry Beaver Creek. The area is approximately 1804 acres, or a little under 3 square miles. The small watershed draining into Stoneman Lake is adjacent to the south. Elevation ranges from about 7800' on Lake Moutain to 6900' at the location of the former stream gage. The watershed is generally asymetrically elliptical with general aspect and drainage to the west. The primary drainageway is approximately four miles in length from the stream gage to the top of the watershed. Terrain is mostly gentle, with the exception of the slopes of Lake Mountain and the drainage way.

Surface geology is dominated by Tertiary and Quaternary volcanics, predominantly basalt. A number of different basalt flows have occurred creating a "shingling effect". Benfer and Beus (1968) reported that approximately 13 percent of the watershed has a cinder cover (overlying basalt).

Soils are predominantly Eutroboralfs and Argiborolls. TES mapping identifed 8 different mapping units being present in the watershed. Vegetation is predominantly ponderosa pine associated with Gambel oak. Two open meadows are present, the larger one being predominantly on private land.

The watershed is located in some of the highest precipitation and water yield area within the ponderosa pine zone. Twenty-five years of precipitation data (water years 1958-82) had a mean annual precipitation of about 28 inches, with approximately 70 percent in the winter period (October-April) and the remaining 30 percent in the summer (May-September) months. There was a substantial variation, with annual precipitation ranging from a high of 46 inches in water year 1973 to a low of 17 inches the following year. Water Year 1973 had both the highest winter and annual precipitation plus the lowest summer precipitation -- about 42 inches as winter precipitation followed by only 4 inches in the summer.

Water yield measured as runoff at the stream gage averaged 6.5 inches in the 15 years prior to treatment, ranging from a low of about 0.5 inches to a high of 23 inches. The median was only about 3.5 inches, or about 55 percent of the mean. Like other areas dependent on storm flow and snow melt without perennial base flow, a few very high years created a mean significantly higher than the median or point at which half of the years are above and below. This is particularly the case on some of the records of this short a duration.

Fig. A-3. Beaver Creek Watershed 8 Winter Precipitation and Annual Runoff

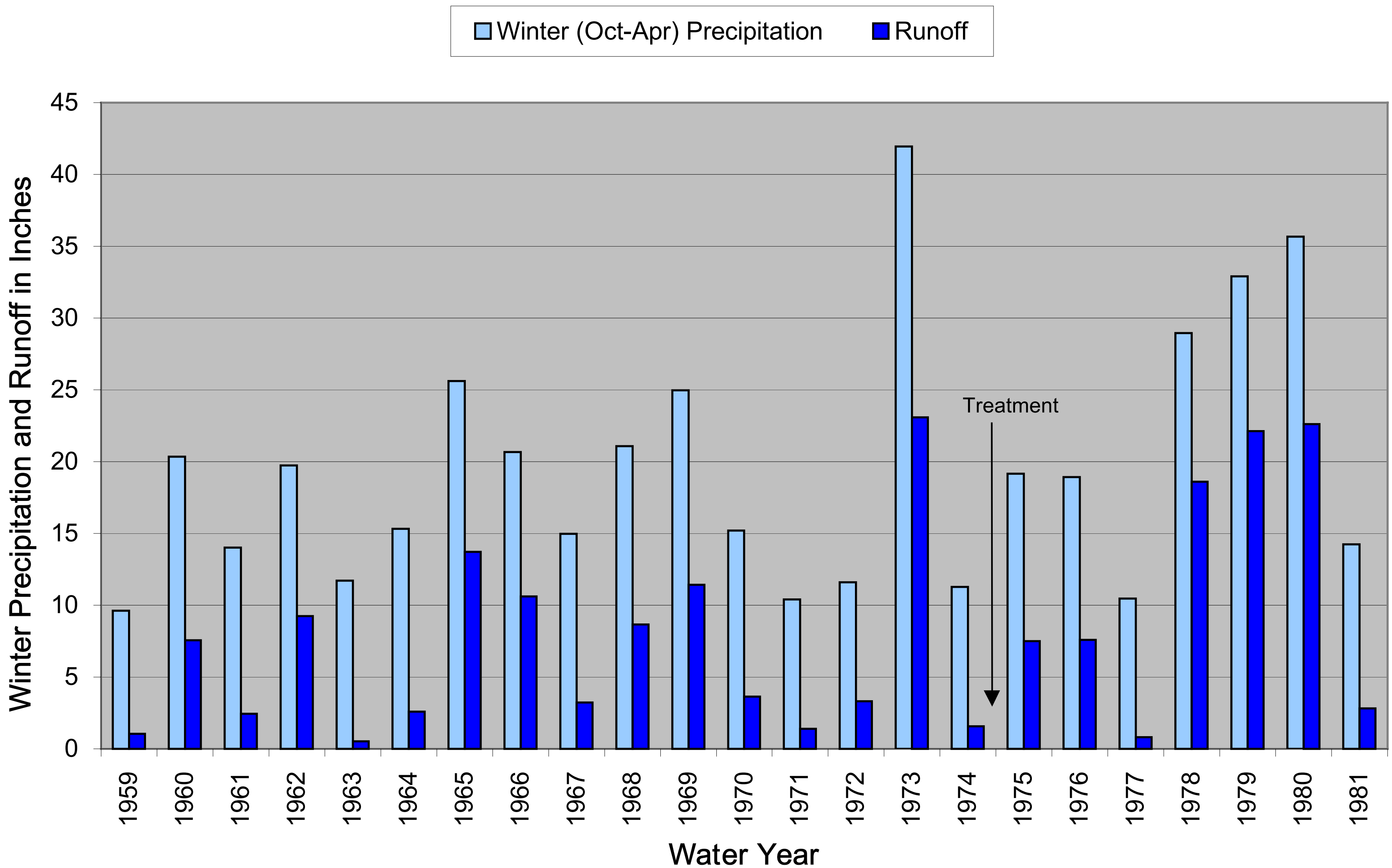

Fig. A-4. Watershed 8 Precipitation Disposition

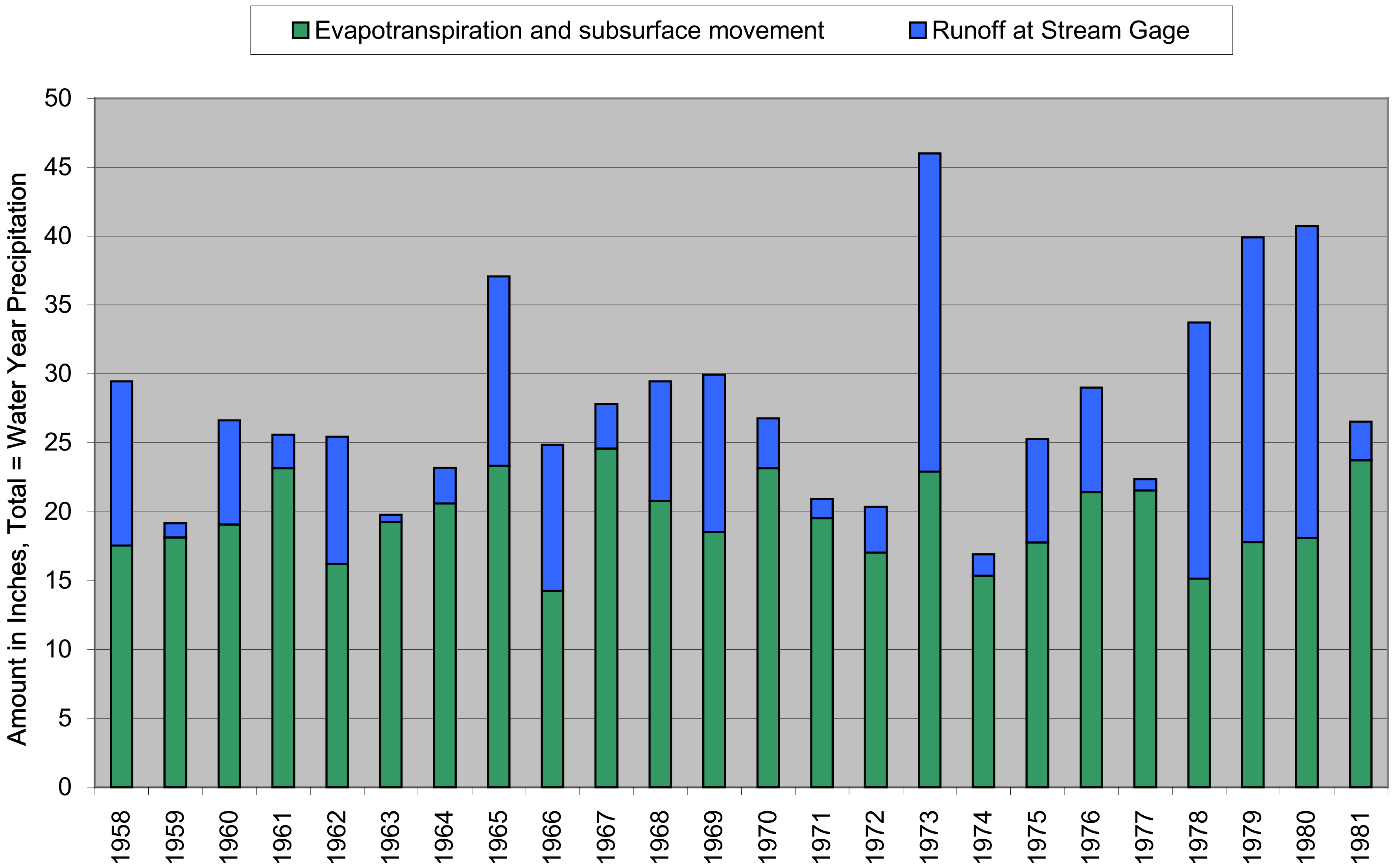

Figure A-3 illustrates seasonal precipitation and runoff for Watershed 8. Runoff is produced very predominantly by winter precipitation -- rain, rain on snow events, and snowmelt. Figure A-4 illustrates the water balance in another manner -- total precipitation is divided into that which runoff and the residual which is a combination of evapotranspiration plus any subsurface movement not detected at the stream gage. It is believed that there is only a limited amount of subsurface flow. The evapotranspiration component varies depending on the patterns of precipitation and the availability of moisture throughout the growing season.

Land use. Land uses are typical of hundreds of thousands of acres of ponderosa pine in the higher elevations of the Middle Verde Watershed. General multiple use is present with timber harvest, livestock grazing, dispersed recreation, and hunting all being uses. In 1957 it was included in the Beaver Creek Research Watershed program, initially being a control for Watershed 9, which was treated in 1968. Then in 1974 it received a silvicultural treatment to reduce overall tree density. This was done through a timber sale. More recently a portion of it was thinned through the Lake Timber Sale in the mid 1990's.

The majority is managed as a part of the Coconino National Forest. Approximately 110 acres are privately owned, as part of a previous homestead. On this private land is located an organization camp and several cabins used seasonally.

Roads include approximately 1 mile of the Stoneman Lake road which passes through southeast corner. It is cinder surfaced and periodically graded by Coconino County. Approximately 9 miles of additional roads were identified, most being native surface material, single lane and not regularly maintained. Cinders are used on those providing access to and within the private land. Several on National Forest have had attempts to be closed out with berms and rock barriers; however the barriers have been circumvented and some vehicular traffic is occurring.

The area receives some seasonal grazing during the warm season -- late spring to early fall.

There is one major earthen stock tank within the watershed, Butch Tank. It is located along the primary streamcourse and has a drainage area of about 1,010 acres, or about 56 percent of the watershed.

Current Conditions – The area was compared to TES evaluations with field inspection to evaluate if the TES units within the watershed were represented by the average conditions for the TES unit. On 5 of the 8 units it was found that current protective ground cover exceeded that shown as the TES average. On three units, comprising more than half of the watershed, field review found current ground cover to be essentially at the “natural” condition. Table A-6 displays the soil condition ratings from the TES along with the calculated soil loss rates from USLE. (Current soil loss calculations for units 575.2, 582, and 584 were adjusted to equal natural as the ground cover percentage was equal to natural).

All TES units were rated as satisfactory. This rating was supported by field observations.

TABLE A-6. BEAVER CREEK WATERSHED 8 SOIL CONDITION RATINGS

TES#	Acres	Condition rating	USLE SOIL LOSS CALCULATIONS tons/ha/yr[7] [8]			
			Potential	Natural	Current	Tolerance
50	4	Satisfactory	11.2	0.	0.4	2.2
55	45	Satisfactory	4.9	0.1	1.9	9.0
565	110	Satisfactory	39.1	1.6	3.4	9.0
575.2	27	Satisfactory	18.9	1.3	1.3	4.5
582	770	Satisfactory	3.3,2.9	0.1,0.1	0.1,0.1	9.0,9.0
584	255	Satisfactory	30.3,22.5	0.4,0.3	0.4,0.3	6.7,9.0
585	330	Satisfactory	2.3,1.0	0.1	3.3, 3.8	6.7, 4.5
586	263	Satisfactory	3.5, 2.9	0.1,0	0.4,0.2	6.7,4.5
Total	1804					

[7] USLE calculations for soil loss rate:
potential– with no protective cover. This is the maximum rate.
natural – with cover that would occur under conditions associated with a climax class
current – with current cover
tolerance – allowable soil loss while sustaining inherent soil productivity

[8] Most TES units have two or more components identified. The TES report describes and gives USLE calculations for the two largest in acreage. Where two numbers are given under the categories of potential, natural, current, or tolerance they represent the two components of that TES mapping unit with the first being from the component having the largest acreage.

A very limited amount of localized erosion and soil movement was observed on a few segments of unmaintained roads. However, due to the generally low slopes and low drainage density they did not appear to be having significant effects on any stream channels.

Channel Conditions – All of the channel observed is in stable condition. The channel downstream from Butch Tank is quite rocky with cobbles, boulders and bedrock outcrops very common. At the time of field inspection in 2001 it had been several years since general major floods in the area. Shrubs and herbaceous vegetation were present between rock surfaces in much of the channel's wetted perimeter.

Water Yield – As discussed under General Description, a streamflow gage was constructed in 1957 and records are available for water years 1958-1981. Initially it was used as a control (untreated) watershed for the adjacent Watershed 9 which was treated in 1968. After allowing 6 years of evaluation of the treatment of Watershed 9, Watershed 8 was treated in 1974 with a general thinning of about one-third -- from about 120 square feet/acre of basal area to about 80. (Basal area is the cross-section of a tree trunk near its base, normally at 4.5 feet above the ground. It is normally expressed in the total square feet per acre. For example, about 75 trees of 14 inches diameter would equal 80 square feet of basal area, 45 trees of 18 inches diameter or 145 trees of 10 inches diameter would equal 80 square feet of basal area, etc.). Figures 13, 14, and 15 (pages 54-56) illustrate the comparison with Watershed 13, its control watershed.

The first two years after treatment had increases slightly greater than the standard error of the regression of prediction, the third year – the driest winter in the record – the yield was very slightly less than predicted. The fourth through sixth years were the three wettest consecutive winters in the record. In all three the water yield was significantly greater than pre-treatment regression. The seventh year had a very dry winter and there was no detectable increase.

Opportunities for Watershed Improvement - Field review of watershed 8 in 2001 found that it has a varying tree density, having had a portion treated with a timber sale in the 1990's. Baker (1986) recommended that the highest potential for increasing measurable runoff might be on north facing slopes adjacent to stream channels. Such sites reviewed in the watershed were found to be fairly dense. Past thinning of ponderosa pine had resulted in stimulating the growth of Gambel oak and New Mexico locust, thus reducing potential water yield increase from pine thinning. There are some relatively dense stands on the slopes of Lake Mountain. Beus (1968) reported this to be a gravity low indicating this cinder cone has "minor or no basaltic plugs beneath". Thus any increase might go to ground-water recharge and be undetectable, though nevertheless of long term value.

Cougar Park Subwatershed

General description. The Cougar Park sample subwatershed is located south of the town of Williams and is within the Kaibab National Forest, within Coconino County. It is in the headwaters of Hell Canyon, tributary to the Verde River downstream from the

Paulden gage. Comprising about 4835 acres, or about 7.6 square miles, it drains to the west. However, the long axis of the watershed is north-south. The site of the USGS stream gage, Hell Canyon near Williams (#0953720), which was operated for water years 1966-72 is about 2.5 miles downstream. The Cougar Park watershed makes up a little over half of the area gaged by that site.

The longest drainageway is approximately 5 miles in length from its highest point to the lower end. The overall pattern of terrain is gentle, interspersed with a number of cinder cones. Elevation ranges from about 6980' at the lower end to 7800’ on Summit Mountain in the southeast corner.

Surface geology is volcanic with basalt flows and cinder cones dominant. Two fault systems cross the watershed, intersecting in the Barney Flat area (Pierce, 2001, Fig. 9). The Mesa Butte fault system is northeastward-trending, while the Cataract Creek fault system is northwestward-trending.

The TES survey identified nine mapping units within the watershed. They are predominantly argiborolls and eutroboralfs, most having a montmorillonite clay component. Surface textures vary from loams to clay loams, with some being quite cindery or cobbly.

Vegetation is predominantly ponderosa pine associated with Gambel oak. About 15 percent of the watershed is in TES units with vegetation of mountain grassland -- Kentucky bluegrass, Arizona fescue, and mountain muhly being the most common.

The Hell Canyon stream gage was operated for 7 water years -- 1966-72. Measured streamflow averaged 3.02 inches per year for that time period but varied from 0.27 inch to 6.41 inches. For comparison, for this same period of time Beaver Creek Watershed 8 averaged 6.03 inches and its control, Watershed 13 (at a slightly lower elevation) averaged 3.29 inches. For comparison over a longer time scale flow the Verde River for this same period -- water years 1966-72 -- averaged below its long term mean of over 100 years but at essentially its long term median, i.e., the amount which 50 percent of the years exceeded. Previous studies of the area (Avery 1989, Thompson 1993) have assumed equal contribution across the watershed above the Hell Canyon stream gage. This may be the case; however, the area of highest elevations, i.e., the southeast quadrant of Bill Williams Mountain, is not included in the Cougar Park watershed, as it drains into Hell Canyon between the gage site and the point selected as the Cougar Park watershed mouth for this analysis.

<u>Land use</u>. A variety of land uses have and continue to take place on the subwatershed. Livestock grazing has occurred since the late 1800's. It occurs during the warmer months for a 5 to 6 month season between mid-May and mid-November. Timber management practices, including commercial harvest have been done in the area. Dispersed recreation -- especially picnicking and camping -- occurs along a number of the roads. Big game hunting for elk, deer and turkey is also popular. There are two blocks of private land, comprising approximately 140 acres with limited development to date.

The Perkinsville Road passes lengthwise through the watershed from north to south, a length of 4 miles for this double lane paved road.. In addition there are about 4.5 miles of road which has been constructed with an aggregate surface, usually cinders, and about 6.6 miles of low standard, native surface roads, with infrequent maintenance, were identified. This adds up to about 2 miles of road per square mile.

There are several stock tanks developed for use by livestock within the watershed.

Name	Drainage Area Acres	Comments
Aspen	45	Ineffective in capturing or holding water
Shiner	475	On private land, includes drainage area of Aspen Tank
Power	80	
Barney	*	Offset from main drainage
Kundie	70	
Ham	275	
Lockett Spring	850	On private land, includes drainage area of Ham Tank

The stock tanks are in locations on drainages comprising about 1475 acres, or about 30 percent of the watershed. Their aggregate capacity is only a very small fraction of the average annual water yield of the watershed above them; however, they do have some effects on sediment movement.

<u>Current Conditions</u>. Review of the TES report, along with field review, agreed that the areas of ponderosa pine/Gambel oak vegetation are generally in stable condition with hydrologic function resulting in infiltration of rainfall and snowmelt into the soil at rates near what might be considered as "natural levels". However, some surface runoff does occur from monsoon rainstorms, as well as from rain on snow events and some snowmelt.

The mountain meadow vegetative type is not in fully satisfactory condition. More than a hundred years of livestock grazing, with livestock concentrating and being gathered in these open parks, or meadows, has resulted in soil compaction and reduced vegetative cover and productivity. The location of Barney Flat, along the primary transportation artery, and surrounded by higher elevation timbered and rougher country, meant it was a natural choice for livestock gathering and handling from the overall area. In recent years, with more intensive livestock management and less concentration in the meadows, elk numbers have increased and there has been some partial replacement of livestock impact by wildlife impact.

Some impact on watershed condition was noted from road drainage and the numerous areas adjacent to them used for vehicular based dispersed recreation -- primarily camping. However, this was generally local in nature.

Field review of channels found them to be generally stable, consistent with the 85 percent of the watershed in ponderosa pine which is stable. At the lower end of the watershed the channel had some raw banks; however, there was not evidence of downcutting or undercutting of banks. At the time of the study, the drought conditions were such that evidence of flows down the channel were masked by trampling effects by elk -- and some evidence of ATV use in the meadow and across the channel..

Because the majority of the watershed area is stable, as are channels, there was not a calculation of watershed peak flows under current and natural condition. However, the effect of condition on the mountain meadow portion is was calculated using a comparison of storm runoff for current and natural conditions from a 10yr storm of 2.3 inches. TES unit 6, the largest, has a calculated stormflow from current condition that is 50 percent greater than under natural cover, while TES unit 537 is 11 percent higher.

Although there have been timber sales within the watershed the current density is greater than what has been considered optimum for water yield from ponderosa pine. The lack of market for smaller diameter trees has contributed to this situation. However, as discussed for Watershed 8, the opportunities for increase appear to be limited.

Field examination suggested that flows within the watershed appeared to be of less peak flow than from other comparable size watersheds. For example, Watershed 8 is less than half the size of Cougar Park, yet the channel development and evidence of flow suggest proportionately higher flows at the mouth. Comparison of channel gradients indicate an probable difference in streamflow velocity. The primary channels in Cougar Park have a low gradient -- 20 to 25 feet per mile for the first 1.5 to 2.5 miles upstream from the mouth. By comparison, the primary channels in Watershed 8 have gradients of 75 to well over 100 feet per mile. Flows from snowmelt or rain on snow events have the opportunity to spread out over a wider area in much of the drainage through Barney Flat.

The 2001 USGS structural geology study which included the watershed stated that:

> "In the area near Bill Williams Mountain, the volcanic and sedimentary rocks are cut pervasively by near-vertical, laterally continuous, and active normal faults….The faults have broken the near-horizontal consolidated sediments that restrict the vertical movement of water to the regional aquifer. The active faults probably improve the vertical-hydraulic conductivity by providing many open near-vertical conduits to the regional aquifer…"

The location of two major fault systems crossing the watershed, with some of the alignment of major drainages coincidental, suggests the possibility that some ground-water recharge might occur. Maintaining infiltration capacities in the channel and adjacent overflow areas would help facilitate any potential for such recharge. The water table surface estimated from a combination of wells and several geophysical investigative procedures indicates a ground-water divide just to the east and northeast of the watershed with the area of the watershed having a water table gradient in the direction of the Verde (Pierce, 2001, Fig. 15).

Opportunities for Watershed Improvement - The primary opportunity is improvement of the hydrologic condition of the mountain meadow areas, primarily TES unit 6. In addition to enhancing infiltration, improvement of the vegetative cover might improve surface soil structure through increased organic matter and subsurface organic activity.

There may be some opportunity for small increases in water yield -- to surface flow down Hell Canyon to the Verde River and/or to groundwater recharge -- via some reduction of forest density. An evaluation of the needs for ecosystem health and sustainability in light of knowledge gained from the NAU Ecological Restoration Institute and other sources may be warranted.

Big Park Subwatersheds

General description. The Big Park sample subwatersheds are located south of Sedona and are in Yavapai County. They are primarily in the unincorporated community of Big Park (also known as "Village of Oak Creek" based on the name of the original subdivision and country club association; however, this was a marketing ploy rather than description as the development was not near Oak Creek nor within the Oak Creek watershed.)

Although not contiguous, the subwatersheds are separated by a narrow area of only 1/4 to 1/2 mile. Both drain to Jacks Canyon, an ephemeral drainage tributary to Dry Beaver Creek. The two watersheds, identified as Big Park East (BP East) and Big Park West (BP West) are 2.7 and 2.9 square miles, respectively, in size. Table A-6 gives a comparison of descriptive statistics:

Table A-6. Characteristics of Big Park East and West Subwatersheds

Characteristic	Big Park East	Big Park West
Size in square miles	2.7	2.9
General watershed shape	Triangular	Rectangular
Highest and lowest elevation	5950, 4030	4990, 3940
Length of longest channel	3.7 miles	2.5 miles
Gradient of longest channel	350 ft/mile	230 ft/mile
Gradient of first 90% of longest channel	150 ft/mile	110 ft/mile
Percent in alluvial soils	41	55
Percent in sandstone soils	56	16
Percent in basalt soils	3	29
Percent in private ownership	28	59
Acres of turf - golf courses & athletic fields	5	165

The subwatersheds are in the Sedona red rock country, and portions of both Bell Rock and Courthouse Butte are within BP East. Sediments of Paleozoic age, primarily in the Schnebley Hill and Supai formations make up these areas celebrated for their scenic attraction. The western and southern sides of BP West are mesas with basalt capping the underlying sedimentary formations.

The natural vegetation of the area is pinyon-juniper woodland and associated desert shrub communities. A major area of alluvial soils was in a generally open (untreed) condition when first settled and was named "Big Park".

Although there is a major contiguous area of private land, it is totally surrounded by National Forest and was not included in the Sedona area mapping by the Natural Resources Conservation Service (NRCS). However, it was included in the Forest Service TES, utilizing aerial photo interpretation for mapping on the private land. The TES identified seven mapping units, of which 5 occurred on private land. Nearly 90 percent of the private land is located on TES unit 403 which occurs on alluvium. This is a result of selecting areas for homesteading which appeared to be the most suitable for agriculture.

<u>Land use</u>. Historically, the area was used for livestock grazing, beginning in the late 1800's. The areas with flatter ground, on alluvial soil were mostly homesteaded in the late 19th and early 20th centuries. As a result of periodic drought most of the homesteaded areas were eventually sold for residential development. An aerial view in the June, 1966 Arizona Highways shows gravel roads and a few scattered residences, primarily the remnants of homesteads. By 1972 when orthophoto quads were published, a golf course had been installed and the Village of Oak Creek subdivision streets are mostly visible. Growth accelerated through the 1980's and 90's and another major golf course was constructed, along with country club and adjacent residential development.

Arizona Highway 179, the primary entrance to Sedona when traveling from Phoenix, passes through BP East, a distance of 1.5 miles.

Rapid urban development has, and continues to occur on the private land in both subwatersheds. On the National Forest portion, especially BP East, very heavy recreation use occurs due to the spectacular views of red rock outcrops. A portion of these red rocks are within the Munds Mountain Wilderness. A developed trailhead and about one and one-half miles of the Bell Rock Pathways trail system is within this subwatersheds.

<u>Current Conditions</u> - Most of the area has been changed from its "natural" condition. Both historic land uses -- livestock grazing on the National Forest and both livestock grazing and some dryland farming on the private land -- and more recent impacts of heavy recreation use on National Forest and urban development on the private land have resulted in these changes. On the developed land most effects have been to increase storm runoff from newly created impervious surfaces of rooftops, driveways, sidewalks, streets, and parking lots. However, some practices can reduce storm runoff, depending on soil conditions and the practices. Figures 11 and 12 (pages 49 and 50) display the calculated differences between two soil units which occur in these two subwatersheds, both developed from the red rock formations in the area. Unit 403.2 is a deep fine sandy loam and is in Hydrologic Soil Group B, while unit 458.2 is a quite shallow and extremely gravelly sandy loam, rated group D. As displayed in Figures 11 and 12 the effects of development are much more pronounced on the group B soil. Although there is some difference between current and natural on 403.2 the degree of historic and current

human use is unlikely to allow it to achieve that condition in the foreseeable future. Picking a midpoint frequency, the 10 year storm, paved areas have a calculated yield of about five times the amount of runoff as current undeveloped conditions. By contrast, turf areas – golf courses, park areas, etc. – produce only about 15 percent of the current condition. Areas which are mulched, e.g., gravel or decomposed granite spread over an area without an impervious barrier from the soil, produce no runoff. Using the differences, the relative amounts of surface area to maintain a balance of no net change can be calculated. In this example one acre of impervious surface would be counterbalanced by 4.3 acres of turf or 3.7 acres of mulched area*. By contrast on the hydrologic D soil, 458.2, it would take 6.6 acres of either turf or mulch to compensate for the increased runoff from one acre of roof and/or pavement.

A comparison of the east and west Big Park watersheds bears this out. In their natural condition (prior to development) the calculated peak flows are quite similar. However, a look at the channels both from aerial photos and in the field indicates the east to have more flashy flows, apparently due to the amount of contiguous sandstone outcrops and steep slopes with very shallow soils overlying sandstone. In addition, a differential development has occurred. On both the primary development has occurred on the Hydrologic Group B soil, 403.2. On the east side there is an outlet mall with paved parking area, more dense housing areas, and commercial areas with motels, and retail areas. On the west there are one golf course and the majority of a second, school play and athletic fields, plus a generally lower density of housing – a large number having a gravel mulch for primary landscaping. Analysis from the Yavapai County GIS system found 165 acres of turf in BP West but only 5 acres in BP east. An examination of the two channels reflects a major difference. The east channel is actively eroding downstream from the developed area and has flooded its banks recently. The west channel appears quite benign by comparison, with little evidence of erosion or major flood flows.

<u>Opportunities for Watershed Improvement</u> - As discussed under current conditions, there are opportunities for watershed improvement on the private land through the manner and location of landscaping and open space features. However, addition of additional turf creates additional water use in an area where there are concerns about the overall (Verde Valley) long-term water supply and maintenance of flowing streams and riparian areas. On the National Forest the needs are to reduce impacts of the very heavy recreation traffic -- pedestrian, equestrian, and mountain bike. The red rock soils are quite vulnerable to damage from traffic and obtaining revegetation adequate for soil protection has proven to be difficult and slow. Management which incudes construction and maintenance of trails for traffic and keeping damaging traffic confined to suitable trails, especially bicycles which create continuous ruts conducive to initiating erosion.

*These are calculated differences based on average conditions. They reflect relative differences but should not be used for design purposes. Development design should be based on site specific analysis